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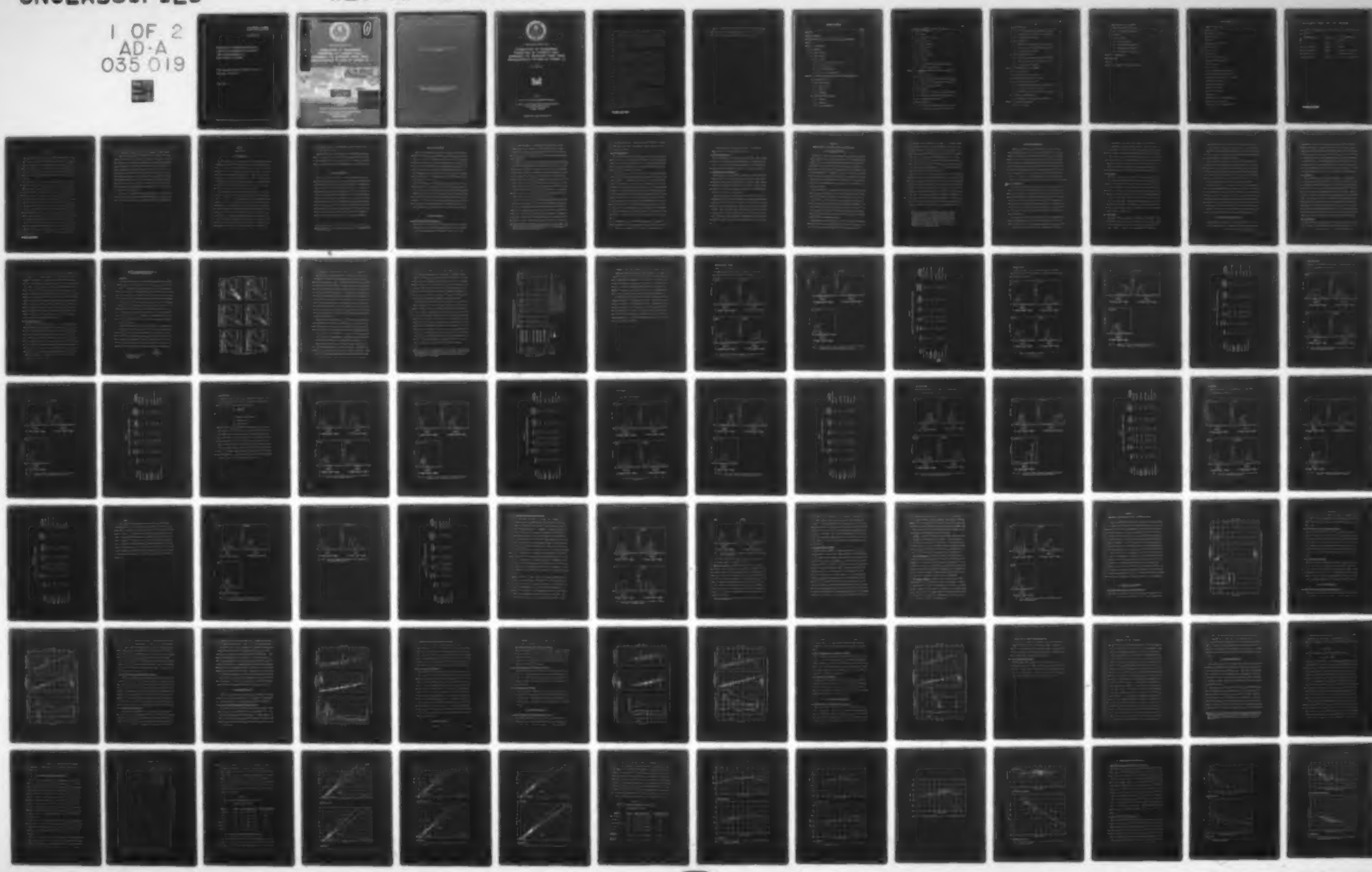

U.S. DEPARTMENT OF COMMERCE
National Technical Information Service

AD-A035 019

CORRELATION OF ENGINEERING PROPERTIES OF COHESIVE SOILS BORDERING THE MISSISSIPPI RIVER FROM DONALDSONVILLE TO HEAD OF PASSES, LOUISIANA

ARMY ENGINEER WATERWAYS EXPERIMENT STATION
VICKSBURG, MISSISSIPPI

JUNE 1974

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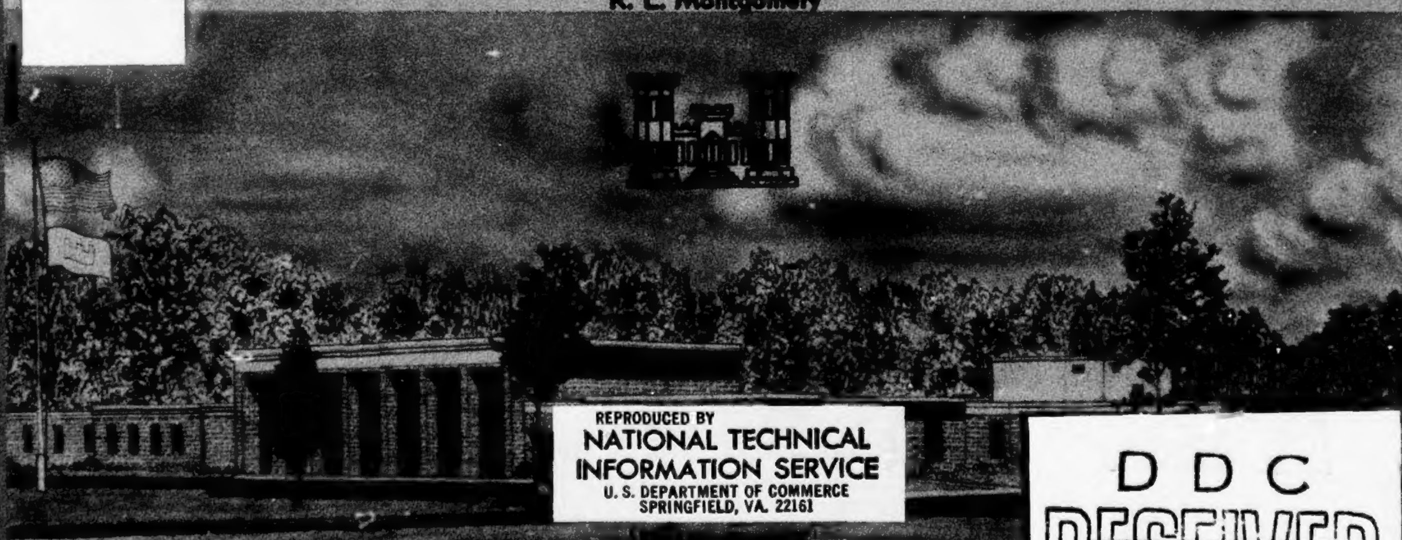
MISCELLANEOUS PAPER S-74-20

CORRELATION OF ENGINEERING PROPERTIES OF COHESIVE SOILS BORDERING THE MISSISSIPPI RIVER FROM DONALDSONVILLE TO HEAD OF PASSES, LA.

by

R. L. Montgomery



June 1974

Sponsored by U. S. Army Engineer District, New Orleans

Conducted by U. S. Army Engineer Waterways Experiment Station
Soils and Pavements Laboratory
Vicksburg, Mississippi

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ARMY-MRC VICKSBURG MISS.

FOREWORD

The study reported herein was authorized by the U. S. Army Engineer District, New Orleans (NOD), on 24 August 1970. The study was conducted for the NOD by the U. S. Army Engineer Waterways Experiment Station (WES) during 1971. The soils data analyzed consisted of existing data from the NOD files. There were no special soil samples taken or tested for this study.

This report is essentially a thesis submitted by Mr. R. L. Montgomery of the Engineering Studies Branch, Soil Mechanics Division, to Mississippi State University in partial fulfillment of the requirements for the degree of Master of Science in Civil Engineering. Messrs. W. L. Hanks and D. E. Lillard, both of the Engineering Studies Branch, made important contributions in preparing graphical presentations and in preparing the report for publication, respectively. Mr. W. C. Sherman, Jr., Research Consultant, provided valuable advice and suggestions. The work was performed under the general direction of Mr. C. L. McAnear, Chief, Soil Mechanics Division. Mr. J. P. Sale was Chief, Soils and Pavements Laboratory.

The author wishes to express his appreciation to Messrs. H. A. Huesmann (ret.), E. B. Kemp, R. P. Picciola, K. J. Cannon, and U. J. Michel, Jr., of NOD for their advice and assistance in collecting the soils data for analyses. The geological profiles presented herein were developed from geological profiles prepared for engineering projects of the NOD by Mr. Kemp, Chief, Geologic Section, NOD.

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Directors of WES during the conduct of the study and the preparation and publication of this report were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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PRINCIPAL NOTATIONS

ALWP	Average low water plane
c	Unit cohesion
c'	Effective unit cohesion
C_c	Compression index
e	Void ratio
G_s	Specific gravity of solids
LI	Liquidity index
LL	Liquid limit
msl	Mean sea level
p_c	Preconsolidation pressure
p_o	Effective overburden pressure
PI	Plasticity index
PL	Plastic limit
Q	Unconsolidated-undrained shear tests
R	Consolidated-undrained shear tests
S	Consolidated-drained direct shear tests
s_d	Drained shear strength
s_u	Undrained shear strength
S	Degree of saturation
w	Natural water content
γ_d	Dry density
σ	Standard deviation (see Appendix A)
ϕ	Angle of internal friction
ϕ'	Effective angle of internal friction

CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows:

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
miles (U.S. statute)	1.609344	kilometers
pounds per square foot	4.88243	kilograms per square meter
pounds per cubic foot	16.0185	kilograms per cubic meter
tons per square foot	9.764859	metric tons per square meter

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SUMMARY

The purpose of this study was to analyze available data on selected cohesive deltaic plain soils and provide summaries of engineering data and correlations of engineering properties according to environments of deposition of the deltaic plain of the Mississippi River. The Mississippi River deltaic plain is that part of southeastern Louisiana that borders the Mississippi River from near Donaldsonville to Head of Passes.

The deltaic plain is a complexly interfingered mass of fluvial, fluvial-marine, paludal, and marine deposits laid down in a variety of environments directly above the Pleistocene. This study focused attention on the deltaic plain deposits that are most important from an engineering standpoint. The deposits selected for study were the natural levee, point bar, and backswamp deposits of fluvial environment and the interdistributary, intradelta, and prodelta deposits of the fluvial-marine environment. Engineering data were obtained from data files on previous field and laboratory investigations of these soils for Corps of Engineers projects. The data were grouped according to environments of deposition based on the geological sections. No additional field or laboratory investigations were undertaken for this study.

The data were collected and arranged in such a manner that it was possible to describe the data mathematically. The best-fit curves or lines, regression equations, and standard deviations presented for the data were developed by use of a computer. Based on the analyses, a

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number of important relations and trends appear to exist for the selected Mississippi River deltaic plain fine-grained cohesive deposits.

Frequency histograms provide summaries of typical soil properties, and correlation plots show the relationships between the different soil properties. A number of correlations were made between Atterberg limits and data from relatively complex and more costly tests for physical properties. Reasonable correlations were found to exist between data from Atterberg limits tests and specific gravity, unconsolidated-undrained shear (Q) strengths, drained shear (S) strengths, and compression indexes (C_c). Also, reasonable correlations between plasticity index and liquid limit were developed for each deposit. Correlations between shear strength increase ratio (s_u/p_o) and plasticity index proved inconclusive.

Important correlations between properties were found for soils of similar geologic origin and depositional environment. However, sufficient data were not available to establish conclusive relationships.

CHAPTER I

INTRODUCTION

1.1 Background

The Mississippi River deltaic plain is that part of southeastern Louisiana that borders the Mississippi River from near Donaldsonville to Head of Passes. The soils beneath the low, flat deltaic plain are primarily cohesive. Unfortunately, these cohesive soils are relatively soft and frequent foundation problems arise. The deltaic plain has been intensively studied by engineers and geologists during past years. Impetus for these studies was basically provided by industrial development along the banks of the Mississippi River and by oil companies eager to exploit the petroleum resources in the area.

During the past few decades, the industrial and cultural development in this region has focused national attention on the economic potential of the river. It serves as means for cheap transportation and provides a source for large quantities of fresh water. Extensive field and laboratory investigations have been made to provide engineering data on the deltaic soils so that foundation designs could be made for industrial facilities and other structures, such as those built for flood control. As a result of numerous foundation investigations in the area, the Corps of Engineers has accumulated an abundance of engineering data on the soils of the deltaic plain. The geologic history and sedimentary patterns of the study area have been intensively

studied in past years and fully discussed by Kolb,[1*] Kolb and Van Lopik,[2] Fisk,[3] and Fisk et al.[4]

Significant advances have been made in correlating engineering properties of some soils, but very few investigations of this nature have been undertaken for the deltaic plain soils. There is a need for summaries of physical properties and engineering correlations of these soils.

1.2 Purpose of Study

The purpose of this study was to analyze available data on selected deltaic plain soils and to provide summaries of engineering data and engineering correlations according to environments of Recent deposition of the deltaic plain of the Mississippi River. Correlations of engineering properties were made which will be useful for design, particularly for planning and preliminary design, of engineering projects. Considerable geological data are available in various reports classifying and describing the major environments of deposition of the Mississippi River Deltaic plain. In this study, summaries and correlations of data are presented to improve understanding of the nature and engineering properties of deltaic plain soils. Correlations between soil properties can frequently be helpful to the engineering designer.

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* Raised numbers refer to similarly numbered items in LITERATURE CITED at the end of text.

1.3 Scope of Report

The Recent Mississippi River deltaic plain is a complexly interfingered mass of fluvial, fluvial-marine, paludal, and marine deposits laid down in a variety of environments directly above the Pleistocene. The scope of this study is to focus attention on those deltaic plain deposits that are most important from an engineering standpoint. The deposits selected for study were the fluvial (natural levee, point bar, and backswamp) and fluvial-marine (interdistributary, intradelta, and prodelta) deposits. The backswamp clays in the Atchafalaya Basin are also included in this study.

Engineering data on the fluvial and fluvial-marine deposits were obtained from data files on previous field and laboratory investigations of these soils. No additional field or laboratory investigations were undertaken for this study. Geological profiles are presented for numerous sites along the Mississippi River mapping the distribution of soil deposits. The soils data are grouped according to environments of deposition based on the geological profiles. Summaries and correlations of engineering data are presented for each cohesive geological deposit.

1.4 Sources of Data

1.4.1 Lower Mississippi River Valley

Study areas for this study were selected from sites of engineering investigations and construction along and adjacent to the Mississippi River between Donaldsonville and Head of Passes, La. Study

areas were selected based on the nature and availability of soils and geological data. The locations of study areas are shown in plate 1 and geological soil profiles are shown in plates 2 through 21. The soils data were grouped into environments of deposition based on these geological profiles.

Generally, the study areas between Donaldsonville and New Orleans, La., are sites of Mississippi River revetment construction or sites of investigations for proposed revetment construction. The study areas below New Orleans consisted of proposed or existing revetment construction sites and areas of proposed grade increases for the main line Mississippi River levees which were planned to provide additional hurricane protection for the low-lying areas of the deltaic plain. A continuous geological profile for the east bank between Mississippi River miles 66.2 and 10.1* is shown in plates 19 through 21. A continuous geological profile for the west bank between Mississippi River miles 66.2 and 10.8 is also shown in plates 19 through 21.

The extensive levee and revetment construction along the Mississippi River has resulted in numerous field and laboratory investigations. These investigations have enabled geologists to develop the geology of the deltaic plain adjacent to the river more completely in recent years. Selected data from field and laboratory investigations and geologic soil profiles were obtained from the New Orleans District, NOD, for this study. The geologic profiles presented in this report were developed from geological studies by Mr. E. B. Kemp of NOD. The

* A table of factors for converting British units of measurement to metric units is presented on page xi.

soils data presented herein were obtained from the files of the NOD and classified into individual environments of deposition based on the referenced geologic profiles.

1.4.2 Atchafalaya Basin

The Atchafalaya Basin backswamp deposits are an alluvial valley feature; however, they developed in the deltaic plain. Because they developed in the deltaic plain and they are a significant foundation feature in this area, analyses of these backswamp deposits are considered within the scope of this study.

In recent years, increased construction in the Atchafalaya Basin has resulted in the accumulation of large amounts of soils data on the backswamp deposits. The NOD has been involved in an extensive levee construction program in this area. The backswamp deposits, however, are relatively soft and generally undesirable as a foundation material. Consequently, settlement and stability problems have been associated with levee construction in areas of these backswamp deposits. To gain a better understanding of the settlement and stability problems involved in levee construction on the soft Atchafalaya Basin soils, the NOD constructed three test sections in typical locations to conduct field studies.[5] The data analyzed and reported herein were obtained from field and laboratory investigations made in connection with these field studies. The general location of the study areas is shown in plate 1.

Identification of the thick backswamp deposits overlying a thicker substratum of sands and gravels was made by Fisk, Wilbert and Kolb.[6] The entire top stratum in this area is backswamp deposits.

Therefore, the presentation of geologic profiles to identify the backswamp deposits is not considered necessary.

1.4.3 Field Investigations

All data analyzed in this report are derived from tests on undisturbed samples. Continuous undisturbed samples were taken with thin-wall, 5-in.-diam, steel-tube piston-type samplers. All borings were made by the NOD. Soil borings are located in plates 2 through 21.

1.4.4 Laboratory Investigations

Laboratory tests were performed by NOD and the Waterways Experiment Station, WES. All triaxial shear data with the exception of the unconsolidated-undrained (Q) shear data were obtained by WES. WES and NOD laboratories performed the Q-tests and all other testing for data presented in this study. No attempt was made to make separate analyses for the data tested by each laboratory.

In general, only those study areas were selected for which sufficient data were available to define soils and geological characteristics adequately. The studies and correlations in this report are based primarily on data from clayey soils; however, no sharp line of distinction between clayey and silty soils was employed in selection of data for this purpose. In general, data from silty soils were included in the correlations and studies wherever it appeared that the value of the correlations or other relations would be enhanced by inclusion of such data.

CHAPTER II

RECENT DEPOSITS AND THEIR PHYSICAL CHARACTERISTICS

2.1 Geological History

The scope of this study does not permit an intensive discussion on the geological history of the study areas. It is recommended that the reader refer to the geological studies by Kolb,[1] Kolb and Van Lopik,[2] Fisk,[3] Fisk, Wilbert, and Kolb,[6] and others for detailed presentations of the geological developments of the study areas. However, a brief abstract is presented to provide the reader with limited information on the geological history which is necessary to set forth the basic geological developments in the study areas. Discussions of geological history presented herein are based on the previously referenced geologic studies.

The Recent deltaic plain deposits are land surfaces built seaward by past deltas and the present delta of the Mississippi River. Each time the deltas extended seaward, the river abandoned its course in favor of a shorter route to the Gulf. During the past 5000 years,[2] seven major deltas were formed that reflect significant changes in the course of the river and are discernible in coastal Louisiana. The result of these shifts on centers of deposition of the great quantities of sediments from the river has been to distribute deltaic sediments in a 200-mile arc[2] in southeast Louisiana.

Delineation of soil conditions in the deltaic plain has gradually progressed from correlation between relatively few soil borings to progressively more valid interpretations made by geologists based on

analyses of numerous soil borings and soils data. In the 1940's Fisk[3] developed the general history of the Mississippi River alluvial valley and developed comprehensive classifications for the environments of deposition characterizing the middle and upper portions of the valley. The lower portion of the valley was investigated only to the extent necessary to establish that in southeast Louisiana the Pleistocene, an ancient horizon with relatively high shear strength characteristics, underlies normally softer Recent sediments. These Recent sediments were collectively classed as deltaic plain soils.

It was not until the 1950's that advances were made in recognizing and delineating some of the environments that make up the deltaic plain sediments. Kolb and Van Lopik[2] studied the deltaic plain sediments and described and classified the deltaic plain environments from the standpoint of their associated engineering soil types. The environments of Recent deposition of the deltaic plain are classified into broad categories of fluvial, fluvial-marine, marine, and paludal environments. These are further divided into individual environments of deposition. This report deals with deltaic plain soil properties separated into their individual environments of deposition. As Terzaghi and Peck[8] point out,

> Two clays with identical grain-size curves can be extremely different in every other respect. Because of these conditions, well-defined statistical relations between grain-size characteristics and significant soil properties such as the angle of internal friction have been encountered only within relatively small regions where all the soils of the category, such as all the clays or all the sands, have a similar geological origin.

2.2 Fluvial Environments

The fluvial sediments are deposited mainly in the inland areas within and along streams and in fresh to brackish waters.[2] They are restricted to relatively narrow bands associated with active streams. Sediments deposited in these areas are further divided into natural levee, point bar, and backswamp deposits. The fluvial environments of deposition associated with the final stages in stream history are further divided into abandoned courses and abandoned distributaries but data were inadequate to present meaningful analyses of these deposits in this study. The depositional characteristics of natural levee, point bar, and backswamp deposits are discussed in the following paragraphs.

2.2.1 Natural Levee

The slightly elevated ridges that occur on both sides of the Mississippi River have been identified as natural levee deposits by geologists. These deposits were formed by near-channel deposition of suspended sediments carried by floodwaters that overflowed the riverbanks. The coarsest of the sediments were deposited near the banks and the finer grain soils were deposited further landward of the banks. Therefore, the grain sizes decrease in the landward direction away from the river. The grain sizes of the natural levee deposit also decrease in a downstream direction.

The height, thickness, and width of the deposit decrease significantly between Donaldsonville and the Head of Passes.[1] The width varies between 4 and 2-1/2 miles between Donaldsonville and New Orleans and becomes significantly narrower south of New Orleans. The growing

process of the natural levees has been altered or stopped by the construction of artificial levees along the river. These artificial levees protect the natural levees from overbank flow during high-water periods, thereby eliminating the source of building materials for the natural levees. The vertical heights of the natural levee have been decreasing because of the process of normal consolidation under its own weight and consolidation caused by the applied weight of the artificial levees. The vertical height of the natural levee decreases from about 20 ft near Donaldsonville to about mean sea level at the Head of Passes.

2.2.2 Point Bar

Point bar deposits are the direct result of lateral migration of the river. During the migration process, erosion occurs from bank scouring, and the coarser materials are redeposited immediately downstream at the convex sides of river bends. The river velocities are considerably less in these areas, and the coarser sediments are readily deposited and form point bar deposits. The rate of lateral migration is much more rapid in the deltaic plain in the vicinity of Donaldsonville than it is downstream. Downstream of Donaldsonville, the river is attempting to scour Recent or Pleistocene clayey materials, which effectively resist erosion. Point bar deposits in the lower reaches of the river are much less extensive.

2.2.3 Backswamp

Backswamp deposits are formed by deposition of sediment in shallow ponded areas during periods of overbank flow. They consist primarily of thinly laminated fat clays and silts, which sometimes have a high organic content. Overbank flows trapped between high natural

levee ridges and other outer boundaries, such as the valley wall, generally result in thick accumulations of sediment. The coarser material from overbank flow settles quickly near the stream, while the finer material settles slowly in low-lying areas as the ponded water gradually drains, evaporates, or seeps into the ground.

Geologists have stated that use of the term (backswamp) is inappropriate for soils downstream of College Point, La. Basically, backswamp deposits are formed from the alluvial valley soils and not the deltaic plain soils. However, the Atchafalaya Basin backswamp deposits formed between two meander belts that bordered an elongated freshwater basin situated in the deltaic plain. Thus, it is an alluvial valley feature, though it developed in the deltaic plain.[9]

Krinitzsky and Smith[10] studied the geology of the backswamp deposits in the Atchafalaya Basin and proposed that, based on deposition and other features, the deposits could be subdivided into correlatable horizons of lake, well-drained swamp, and poorly drained swamp. These correlation horizons were identified through the use of radiography. Radiography also brought out details of fracturing and plastic deformation, including voids and desiccated layers. The backswamp deposits are believed to have been developed continuously over the past 15,000 years in an environment of shallow lakes and low-lying swamps.[10]

2.3 Fluvial-Marine Environments

Fluvial-marine deposits are laid down off the mouths of deltas in fresh to brackish waters.[2] Although the fluvial-marine deposition results in a complexly interstratified deposit, geologists have

subdivided the fluvial-marine deposits into three main environments of depositions: prodelta, intradelta, and interdistributary. Geologists estimate that the fluvial-marine environments make up about 75 percent of the Recent deposit of the deltaic plain. These soils are a significant foundation material along the Mississippi River from New Orleans to the Head of Passes. A good understanding of the geology and engineering properties of fluvial-marine deposits is required before engineers can design foundations on these soils with confidence. The deposition characteristics of the three environments are described below.

2.3.1 Prodelta

The fine-grained deposition swept seaward by the Mississippi River preceding each deltaic advance is the prodelta deposits.[2] They are deposited underwater at the mouth of the river and redistributed by tidal currents. The clays are deposited some distance from the mouth and the silty clays are deposited nearer the mouth. These deposits are the first sediments introduced into a depositional area by an advancing delta. Each ancient delta that contributes to the makeup of the deltaic plain was preceded by a wave of prodelta deposits resulting in a widespread areal extent of prodelta deposits in the subsurface. Mud flats and mud lumps are two phenomena in the deltaic plain that are associated directly with the prodelta deposits. The scope of this study, however, does not permit inclusion of these interesting phenomena.

2.3.2 Intradelta

The continuous seaward advance of the delta results in the deposition of bars of coarser materials over the prodelta deposits. These intradelta deposits form near the mouths of the distributaries when the

current velocity becomes significantly less as the river water joins the Gulf water. The coarser sediments fall from suspension and form distributary mouth bars.[11] Sediments continue to build seaward on the bar crest. Some sediments, however, are distributed as submerged fans on the seaward sides of the bars. As the distributary builds seaward, the bars may be scoured through and a new seaward bar deposited. At times, the channel may split around the bar, resulting in the formation of additional distributary mouth bars. As a result of this bifurcation of the stream channel and the resultant formation of additional bars laterally away from the original bar, widespread wedges of silty sand and sand called "sand sheets"[12] are formed over the deltaic plain. Kolb and Van Lopik[2] found that in most instances, the position of the intradelta deposits in the subsurface is marked on the surface by fairly well-defined abandoned distributaries.

2.3.3 Interdistributary

Interdistributary deposits occur in areas between the past and present channels of the Mississippi River. Where sediment-laden waters flow over the subaqueous or low natural levees, the coarsest material is deposited near the distributaries as part of the intradelta sequence. The finer materials are carried in suspension into the basins between distributaries and settle out. Deposition of interdistributary deposits is very similar to that of the backswamp deposits of the fluvial environment. Fine materials may also be supplied into the interdistributary basins by overflow from the main channels upstream and from materials originally discharged at the mouths of the distributaries and gradually worked inland by tidal action.

2.4 Typical Properties of Fluvial and Fluvial-Marine Environments

2.4.1 General

A considerable amount of field and laboratory data was reduced and separated so that typical properties of each depositional environment could be established. The major portion of the data represents saturated soils because the groundwater table is located near the ground surface at all of the study sites. However, the natural levee deposits probably occur more in a partially saturated state than fully saturated.

The study sites, with the exception of the sites in the Atchafalaya Basin, are located along the banks of the Mississippi River. The groundwater tables established in the geological profiles shown in plates 2 through 21 correspond to the average low water plane (ALWP) of the river at each study site. There was sufficient data for the study sites in the Atchafalaya Basin to establish a groundwater table quite near the ground surface.

Preconsolidation pressures (p_c) were compared to existing effective overburden pressures (p_o), which were based on the groundwater at ALWP, to determine the state of consolidation of the soils. The p_c values were computed from laboratory consolidation tests using the procedure proposed by Casagrande.[8] Values of p_c were plotted versus p_o for each of the deposits, and the results are shown in fig. 2-1. The following criteria were used to define the degree of consolidation:

	Ratio p_c/p_o
Normally consolidated	0.67 to 1.5
Overconsolidated	>1.5
Underconsolidated	<0.67

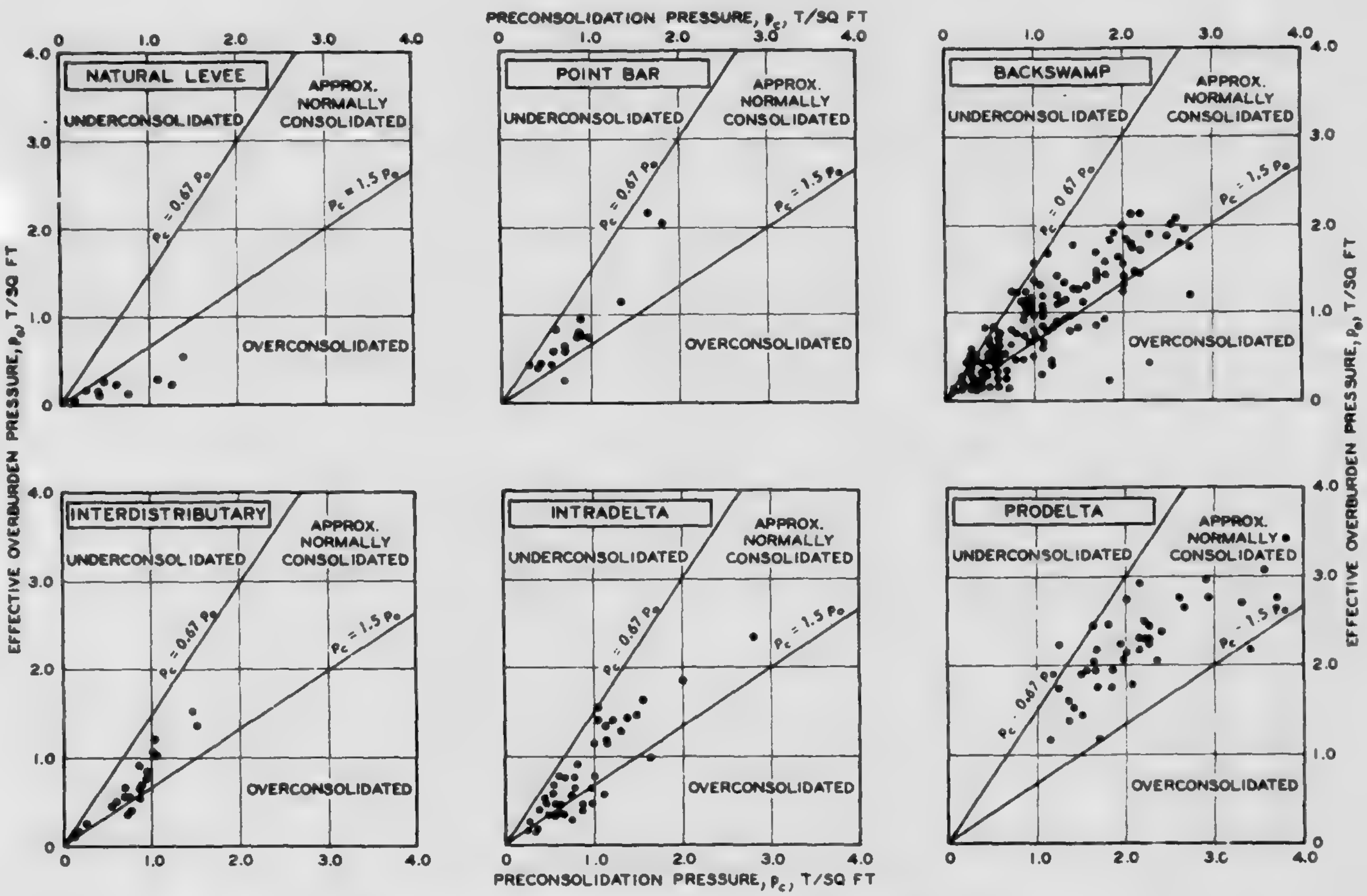

Fig. 2-1. Effective overburden versus preconsolidation pressures

The major portion of the data points falls within the range of approximately normally consolidated soils. However, the natural levee and backswamp deposits have an appreciable number of ratios in the range of overconsolidated soils. Preconsolidation data on the natural levee deposits were insufficient to establish the depth of overconsolidated soils. Sufficient data were available to define the overconsolidated soils of the backswamp deposits. The deposits also experience cycles of wetting and drying as the groundwater table fluctuates. The process of desiccation can result in consolidation, the same as if an external load were applied, and overconsolidation can occur after repeated cycles of wetting and drying.[8] Accordingly, the natural levee clays and the backswamp clays, within the range of groundwater fluctuations, were considered to be slightly overconsolidated resulting from the process of desiccation.

Based on the data shown in fig. 2-1, the point bar, interdistributary, intradelta, and prodelta deposits appear to be approximately normally consolidated. The data also indicate that some of the backswamp soils have not fully consolidated under the existing overburden load. These soils are considered to be slightly underconsolidated but still in the process of consolidating. The data for the underconsolidated soils were not sufficient to permit adequate analyses.

Organic materials were found in various amounts in all the deposits. The backswamp deposits, however, contained considerably more organic materials than the other deposits. Abundant quantities of peat and organic clays containing partially decayed vegetation were present in the backswamp deposits. Since there was sufficient information

available for such identification, the data from backswamp deposits were classified and analyzed as either organic or inorganic deposits. The organic backswamp soils were identified on the basis of visual inspection and plots of plasticity index versus liquid limit. Organic backswamp deposits were included in this study because there is a need for a better understanding of these soils. Peat deposits were not considered within the scope of this study. Organic materials were found in the other deposits, but not in sufficient quantities to warrant division of the data into organic and inorganic groups.

Statistical analyses* were performed on data from selected environments of deposition within the Mississippi River deltaic plain to determine average properties. Typical properties are summarized in table 2-1. Frequency histograms were used as the basis for selection of the typical properties presented herein. Frequency histograms are a meaningful way to present the variation in soil properties so that the researcher (as well as the reader) can draw reasonable conclusions concerning certain typical properties of a given deposit. All of the data plotted as histograms did not form the normal histogram distribution, which is a bell-shaped curve with 68.3 percent of the data (i.e., 68.3 percent of the area under the normal curve) contained within plus or minus one standard deviation of the average. Some of the data showed very erratic distributions when plotted as histograms.

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* Statistical terms and procedures used in this report are briefly defined in Appendix A. References 13-16 are cited as sources of complete definitions and thorough explanations of the statistical procedures used in this study.

Table 2-1

Typical Properties of Selected Environments of Deposition
Within the Mississippi River Deltaic Plain

		Deposit	Grain Size and Organic Content	Natural Water Content %	Liquid Limit %	Plasticity Index %	Liquidity Index	Dry Density pcf	Specific Gravity	Void Ratio e_o	s/p_o Ratio	Shear Strength Q c T/sq ft	Shear Strength R c T/sq ft	Shear Strength R ø deg	Shear Strength S ø deg
Mississippi River Deltaic Plain	Fluvial	Natural levee		18-83 (45)	29-129 (66)	2-90 (42)	0.14-1.18 (0.54)	50-92 (76)	2.62-2.74 (2.69)	0.82-6.16 (1.46)	--	0.08-0.68	0.01-0.50 (0.20)	8-22 (13)	16-31 (24)
		Point bar (silty)		26-79 (44)	31-87 (54)	7-63 (33)	0.22-1.60 (0.74)	54-98 (78)	2.65-2.77 (2.69)	0.70-2.12 (1.12)	0.14-0.37 (0.27)	0.11-1.24	0.01-0.50 (0.20)	8-22 (13)	16-31 (24)
		Backswamp (organic)	Insufficient data	42-367 (127)	58-397 (152)	43-218 (106)	0.16-1.41 (0.70)	16-73 (43)	2.10-2.74 (2.46)	1.36-6.73 (3.11)	--	0.03-0.27	0.00-0.40 (0.14)	7-20 (13)	13-35 (22)
		Backswamp (inorganic)		31-98 (59)	27-148 (83)	19-86 (56)	0.03-1.26 (0.55)	48-91 (65)	2.52-2.75 (2.68)	0.85-2.57 (1.62)	0.07-0.76 (0.26)	0.1-0.72	0.00-0.50 (0.13)	4-27 (12)	13-36 (21)
	Fluvial-Marine	Prodelta		31-70 (53)	39-100 (79)	16-72 (51)	0.12-1.08 (0.51)	49-90 (72)	2.67-2.80 (2.72)	0.84-2.06 (1.32)	0.11-0.39 (0.22)	0.18-0.85	0.01-0.50 (0.20)	8-22 (13)	16-31 (24)
		Intradelta		24-132 (58)	25-212 (77)	5-164 (52)	0.39-1.52 (0.69)	33-98 (67)	2.57-2.76 (2.70)	0.64-2.84 (1.57)	0.07-0.65 (0.29)	0.05-0.4	0.01-0.50 (0.20)	8-22 (13)	16-31 (24)
		Inter-distributary		24-113 (57)	38-179 (82)	19-162 (59)	0.13-1.03 (0.61)	45-94 (66)	1.59-2.74 (2 64)	1.01-2.59 (1.58)	0.22-0.85 (0.37)	0.12-0.5	0.01-0.50 (0.20)	8-22 (13)	16-31 (24)

LEGEND

Clay (0.005 mm)
Silt (0.05-0.005 mm)
Sand (2.0-0.05 mm)
Organic material

Notes:

(1) Numbers in parentheses are average values.

(2) Insufficient consolidated-undrained and drained shear strength data were available for the natural levee, point bar, prodelta, intradelta, and interdistributary deposits. The data shown represent all five deposits.

(3) Insufficient data were available to clearly establish the amount of organic matter typically occurring in each deposit.

(4) Shear strengths are given in cohesion (c), tons per square foot and angle of internal friction (ø) in degrees.
Q denotes unconsolidated-undrained triaxial compression tests.
R denotes consolidated-undrained triaxial compression tests.
S denotes consolidated drained direct shear tests.

(5) Grain-size characteristics based on references 2 and 10.

Frequency curves have certain characteristic shapes. Some of these shapes are described as normal curve, skewed to the right, skewed to the left, J-shaped, reverse J-shaped, U-shaped, bimodal, and multimodal. The degree of peakedness of a distribution is called kurtosis and can be described as leptokurtic, platykurtic, or mesokurtic. Definition of the above histogram descriptive terms are presented in Appendix A. These descriptive terms are used in the following paragraphs to provide standard means for discussing the histograms.

Computation and plotting of the frequency histograms were accomplished by computer. In some areas, the values selected for typical properties represent a minimum amount of data. Nevertheless, the values presented in table 2-1 are considered to be reasonably indicative of the typical properties of each soil deposit and are good empirical data. These data, supplemented by other data presented herein, are considered pertinent to a better understanding of the soils of fluvial and fluvial-marine environments.

2.4.2 Natural Water Contents

Frequency distributions of natural water contents for selected deltaic deposits are shown in figs. 2-2 and 2-3. A summary of natural water content investigations is given in table 2-2.

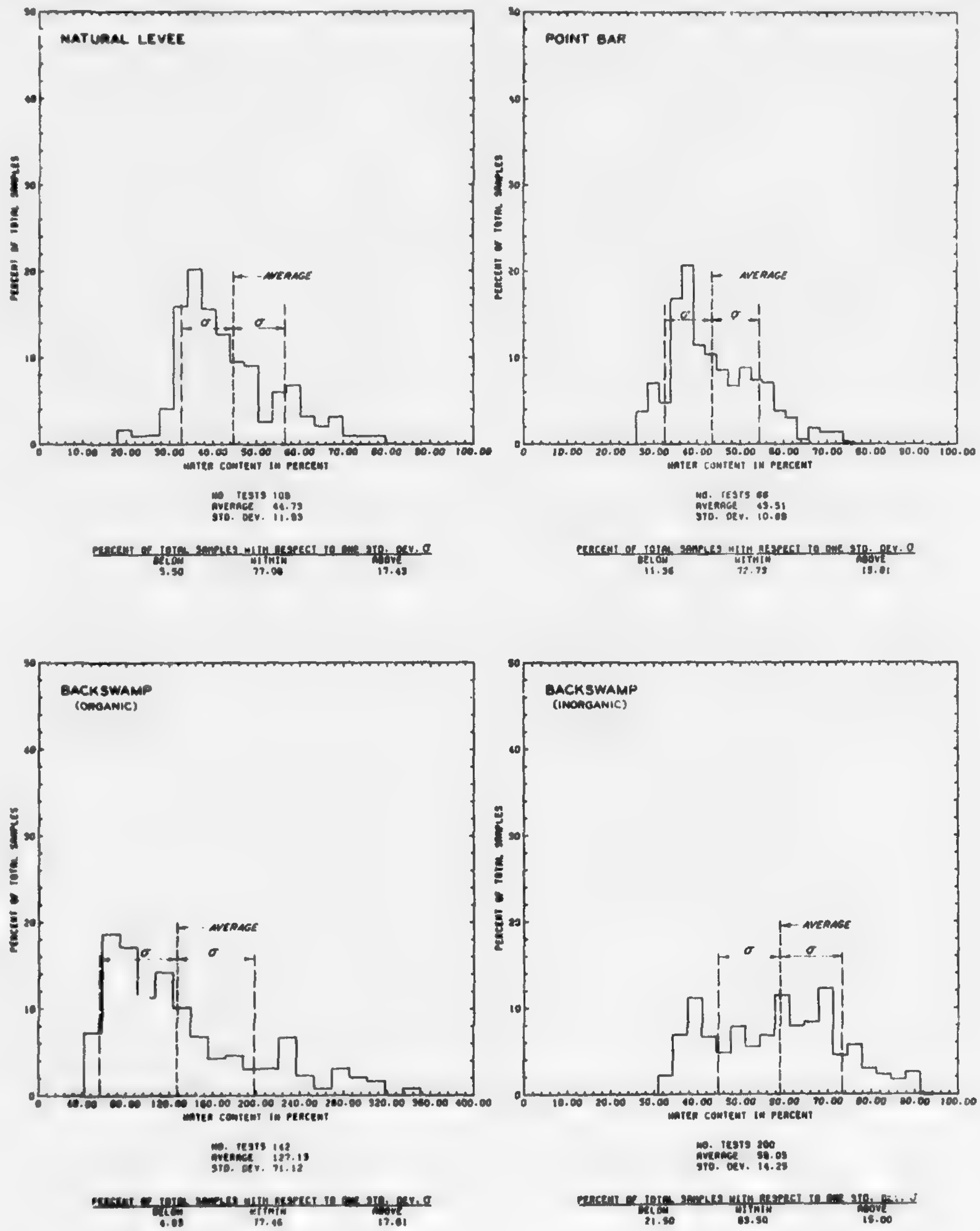

Fig. 2-2. Natural water content frequency histograms for natural levee, point bar, and backswamp deposits

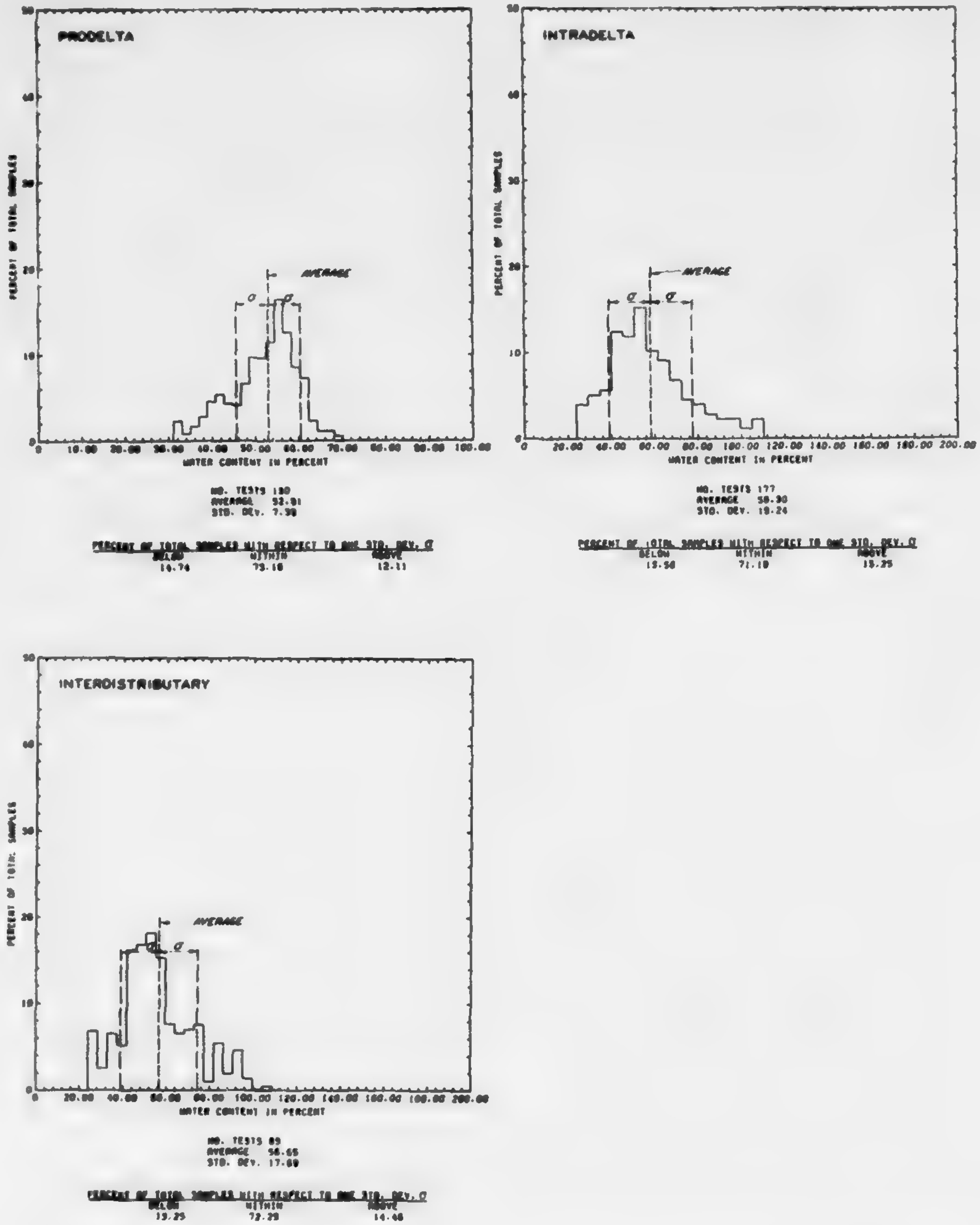

Fig. 2-3. Natural water content frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-2

SUMMARY OF NATURAL WATER CONTENT FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range %	Average %	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-2	109	18 - 83	45	11.9	77.1	Positive Skewness
Point Bar	2-2	88	26 - 79	44	10.9	72.7	Positive Skewness
Backswamp (Organic)	2-2	142	42 - 367	127	71.1	77.5	Positive Skewness
Backswamp (Inorganic)	2-2	200	31 - 98	59	14.3	63.5	Bimodal
Prodelta	2-3	190	31 - 70	53	7.4	73.0	Negative Skewness
Intradelta	2-3	177	24 - 132	58	19.2	71.0	Positive Skewness
Interdistributary	2-3	83	24 - 113	57	17.7	72.3	Normal

2.4.3. Liquid Limit

In figs. 2-4 and 2-5 liquid limit frequency distributions are presented for selected deltaic deposits. A summary of this investigation is presented in table 2-3.

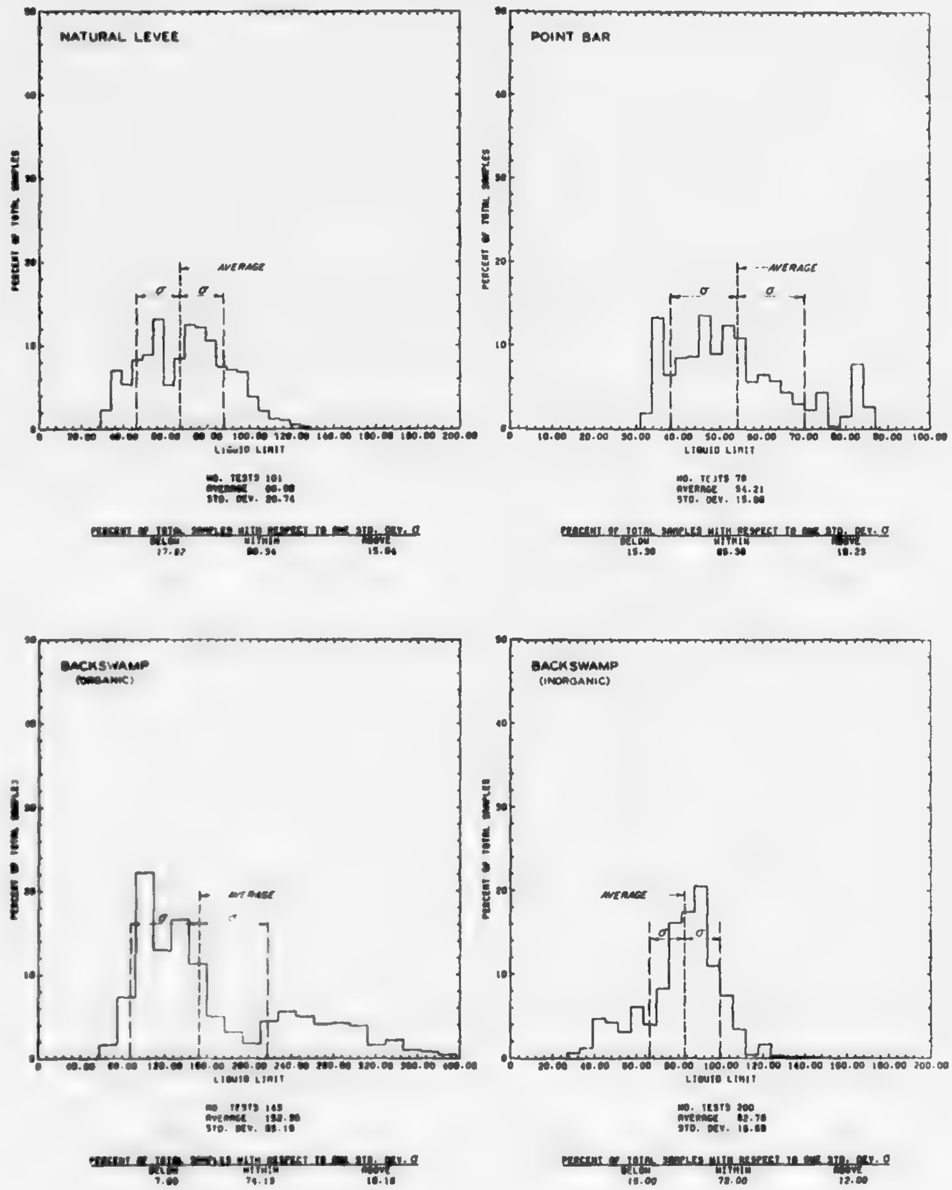

Fig. 2-4. Liquid limit frequency histograms for natural levee, point bar, and backswamp deposits

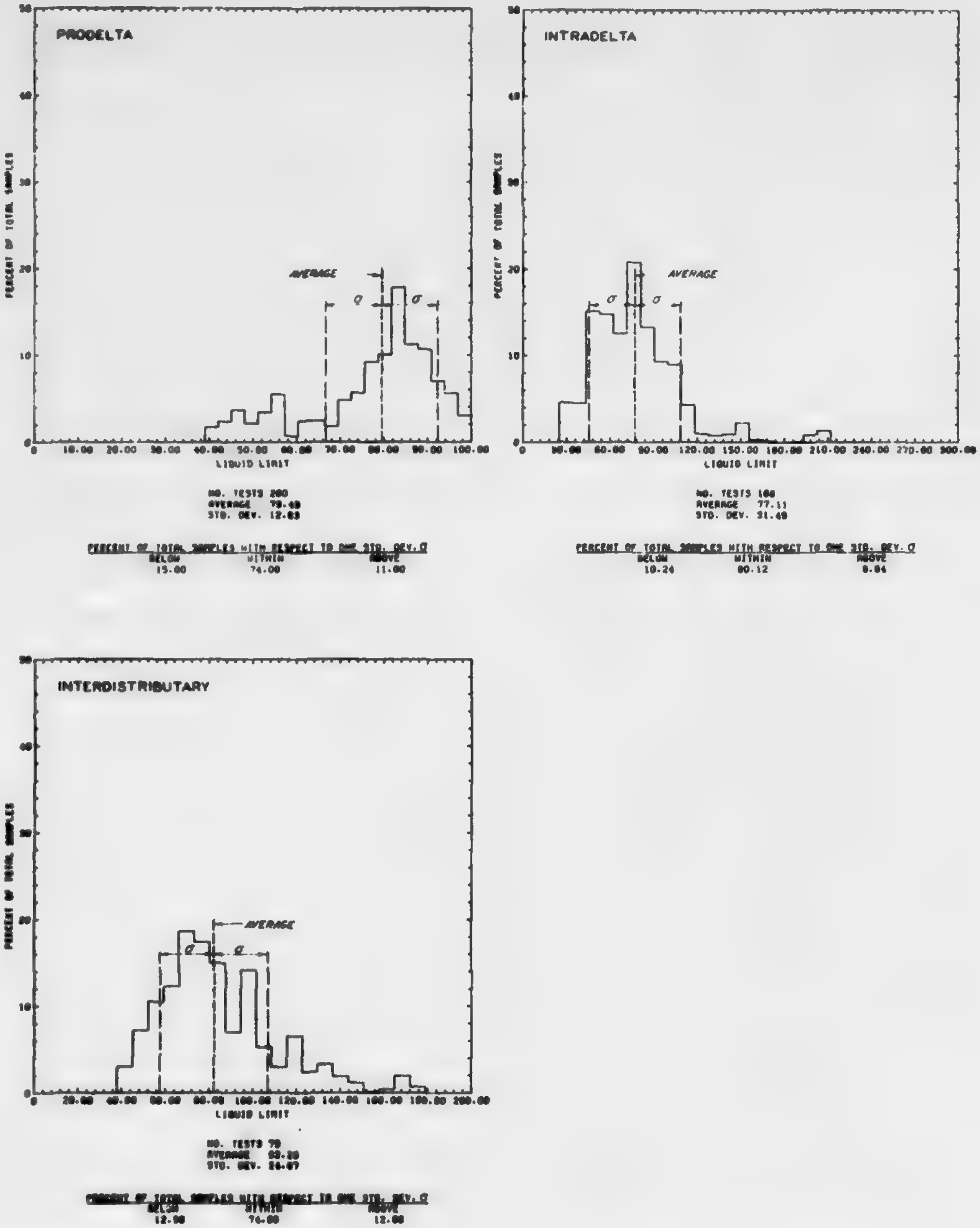

Fig. 2-5. Liquid limit frequency histograms for prodelta, intradelta, and inte.distributary deposits

TABLE 2-3

SUMMARY OF LIQUID LIMIT FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range %	Average %	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-4	101	29 - 129	67	20.7	66.3	Normal
Point Bar	2-4	78	31 - 87	54	16	65.4	Positive Skewness
Backswamp (Organic)	2-4	143	58 - 397	152	65	74	Bimodal
Backswamp (Inorganic)	2-4	200	27 - 148	83	16.7	73	Negative Skewness
Prodelta	2-5	200	39 - 100	80	12.8	74	Bimodal
Intradelta	2-5	116	25 - 212	77	31.5	80	Leptokurtic
Interdistributary	2-5	79	38 - 179	82	24.7	74.7	Positive Skewness

2.4.4 Plasticity Index

Frequency distributions of plasticity index are shown in figs. 2-6 and 2-7, and summarized in table 2-4.

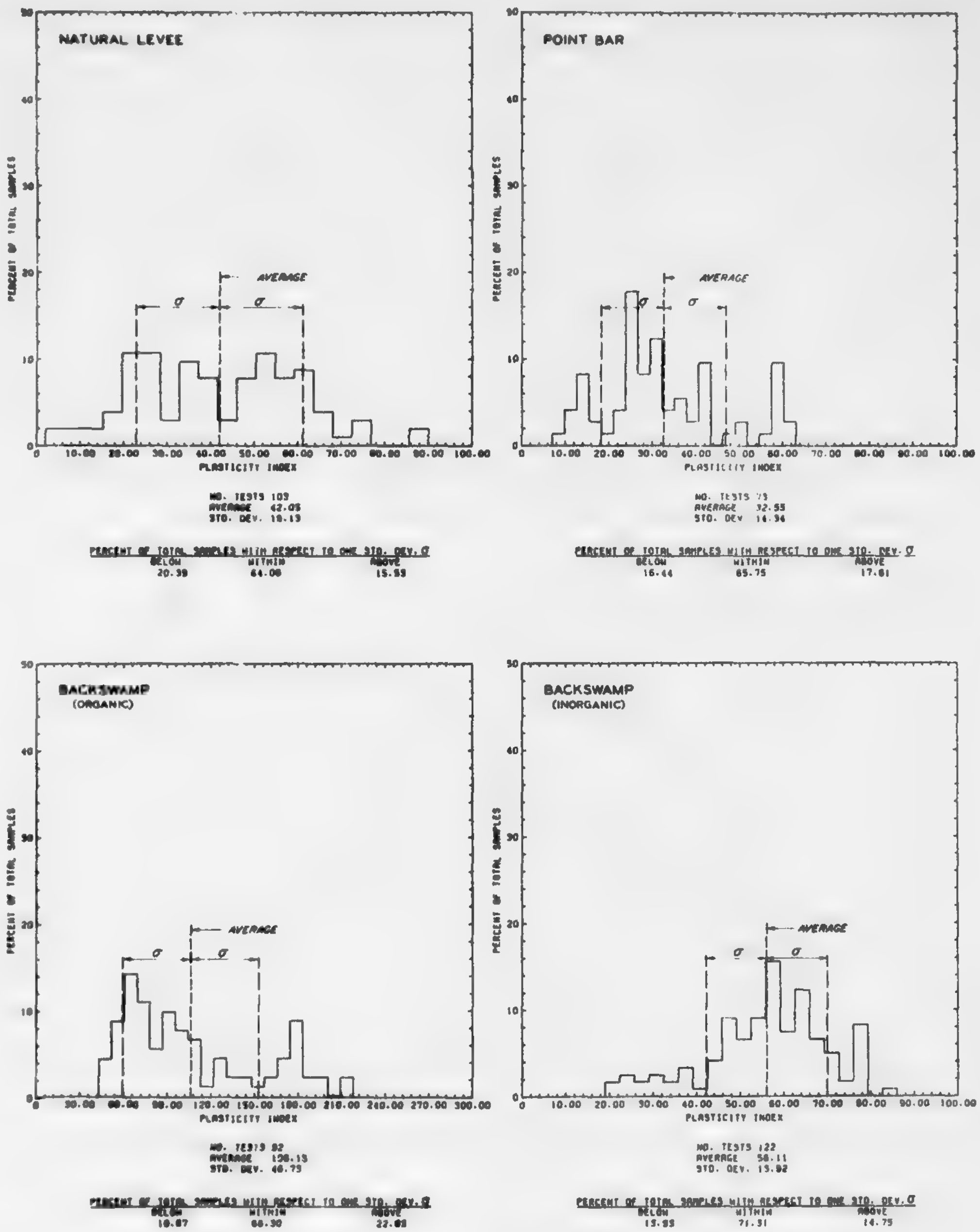

Fig. 2-6. Plasticity index histograms for natural levee, point bar, and backswamp deposits

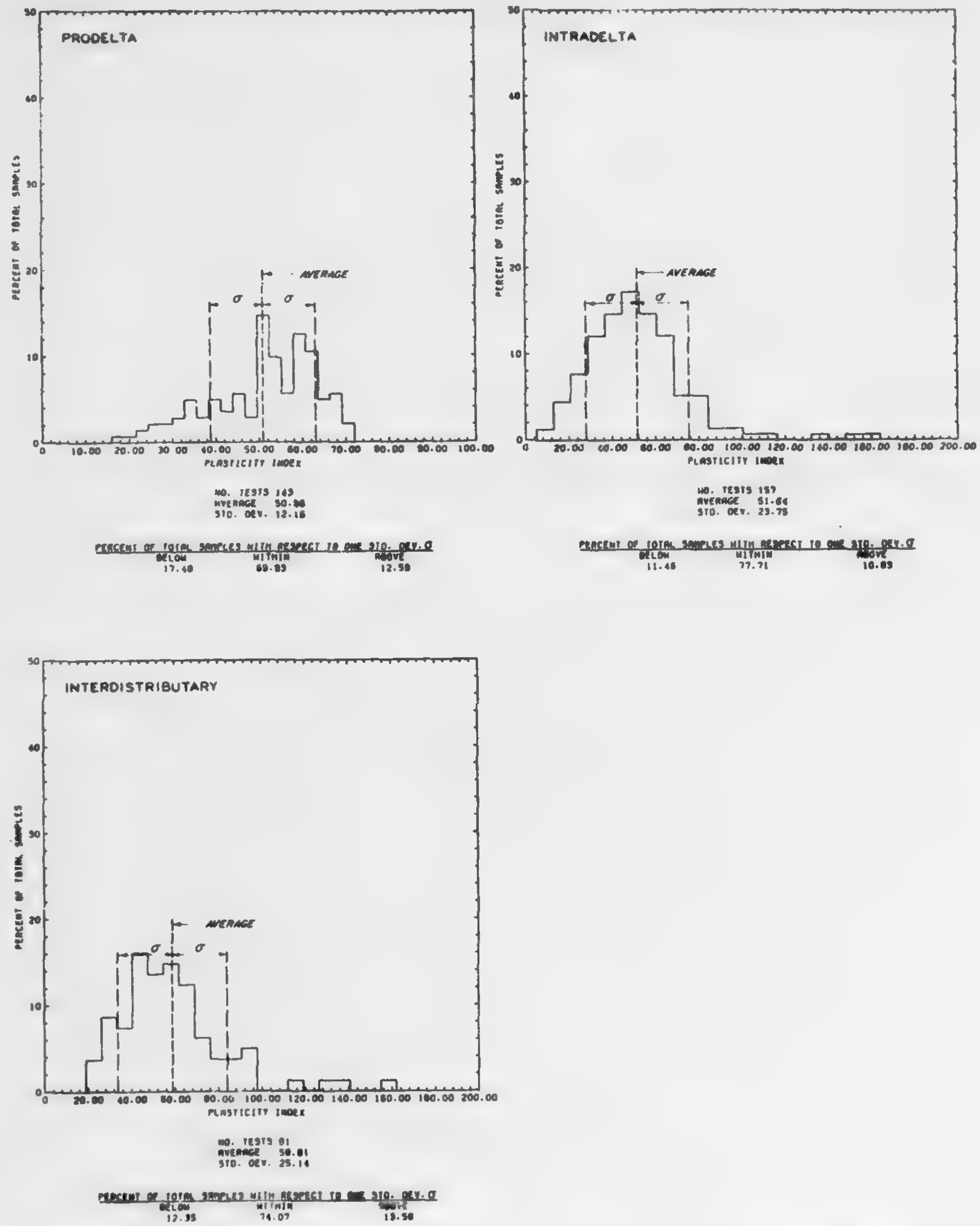

Fig. 2-7. Plasticity index frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-4

SUMMARY OF PLASTICITY INDEX FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range	Average	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-6	103	2 - 90	42	19	64	Multimodal
Point Bar	2-6	23	7 - 63	33	14	65.8	Multimodal
Backswamp (Organic)	2-6	92	43 - 218	106	46.7	66	Bimodal
Backswamp (Inorganic)	2-6	122	19 - 86	56	13.9	71.3	Normal
Prodelta	2-7	143	16 - 72	51	12.2	69.9	Negative Skewness
Intradelta	2-7	157	5 - 164	52	23.8	77.7	Leptokurtic
Interdistributary	2-7	81	19 - 162	59	25	74	Leptokurtic

2.4.5 Liquidity Index

The liquidity index is the ratio of natural water content minus plastic limit to plasticity index. It is possible to compute the liquidity index (LI) from the following equation:

$$LI = \frac{w - PL}{LL - PL} \qquad (1)$$

where:

w = Natural water content

PL = Plastic limit

LL = Liquid limit

The liquidity index is a good indicator of the consistency of a soil. If the natural water content of a soil is greater than the liquid limit, the LI is greater than 1.0; when remolded at constant water content such a soil turns into a thick viscous slurry. If the natural water is less than the plastic limit, the liquidity index is negative. Soil with a negative liquidity index cannot be remolded at the natural water content.[8] The liquidity index is also a useful indicator of sensitivity of clays and of undrained shear strength. This point will be discussed later in paragraph 4.4.1. Frequency distributions of liquidity index are shown in figs. 2-8 and 2-9, and summarized in table 2-5.

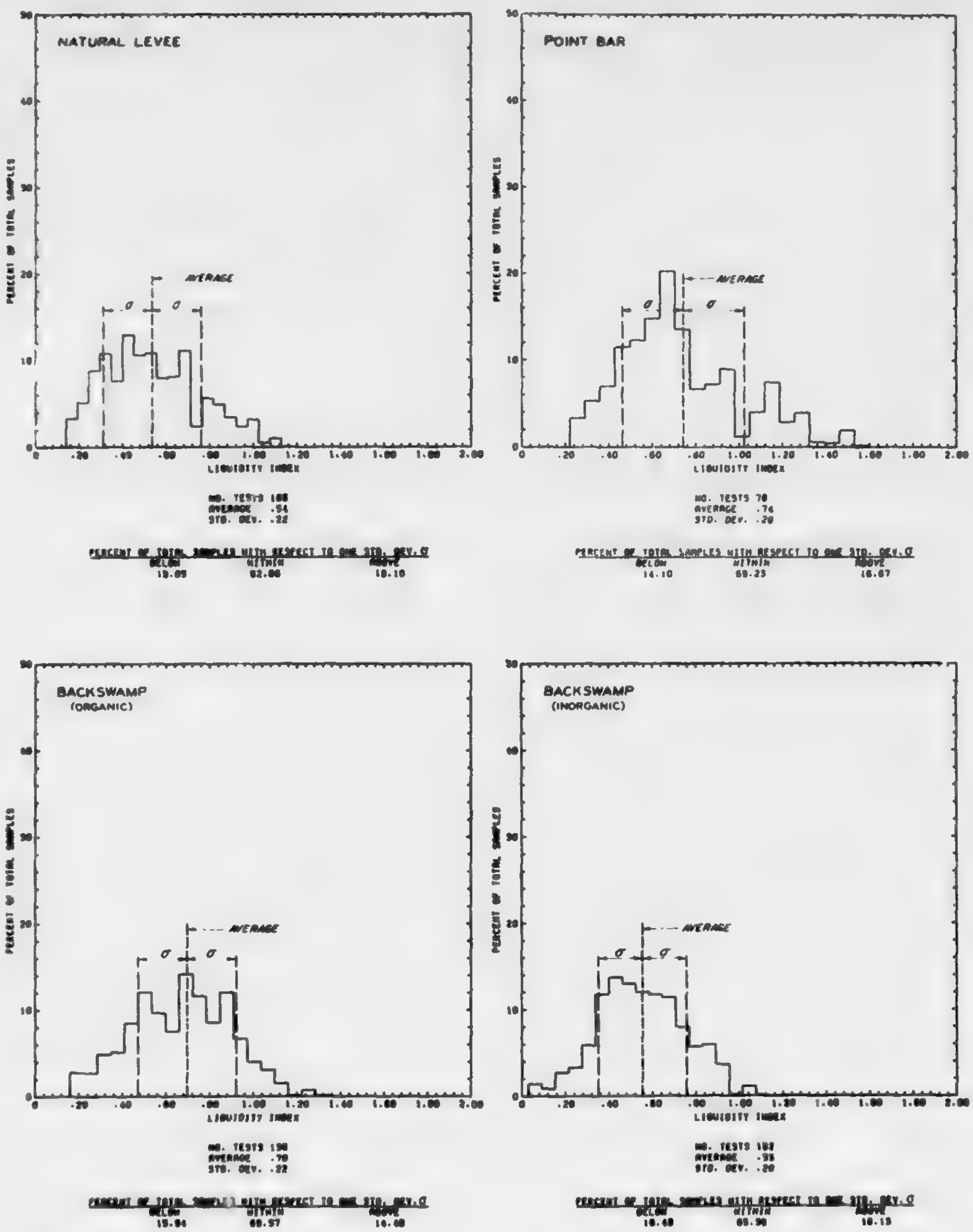

Fig. 2-8. Liquidity index frequency histograms for natural levee, point bar, and backswamp deposits

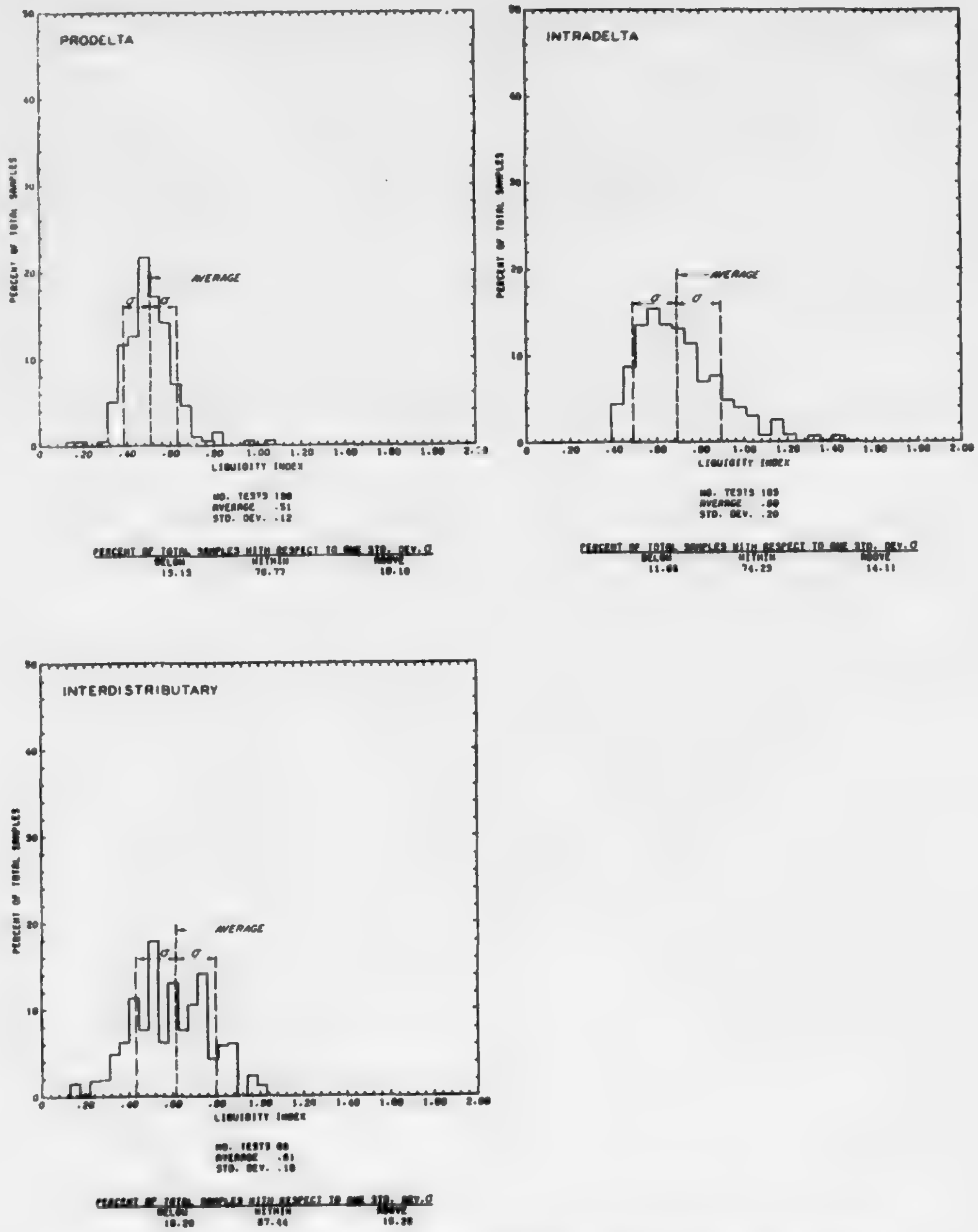

Fig. 2-9. Liquidity index frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-5

SUMMARY OF LIQUIDITY INDEX FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range	Average	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-8	105	0.14 - 1.18	0.54	0.22	62.9	Multimodal
Point Bar	2-8	78	0.22 - 1.60	0.74	0.28	69	Positive Skewness
Backswamp (Organic)	2-8	138	0.16 - 1.41	0.70	0.23	69.6	Normal
Backswamp (Inorganic)	2-8	182	0.03 - 1.26	0.55	0.20	65.4	Normal
Prodelta	2-9	198	0.12 - 1.08	0.51	0.12	76.8	Leptokurtic
Intradelta	2-9	163	0.39 - 1.52	0.69	0.20	74	Positive Skewness
Interdistributary	2-9	86	0.13 - 1.03	0.61	0.18	67.4	Multimodal

2.4.6 Dry Density

Frequency distributions of dry density are shown in figs. 2-10 and 2-11, and summarized in table 2-6.

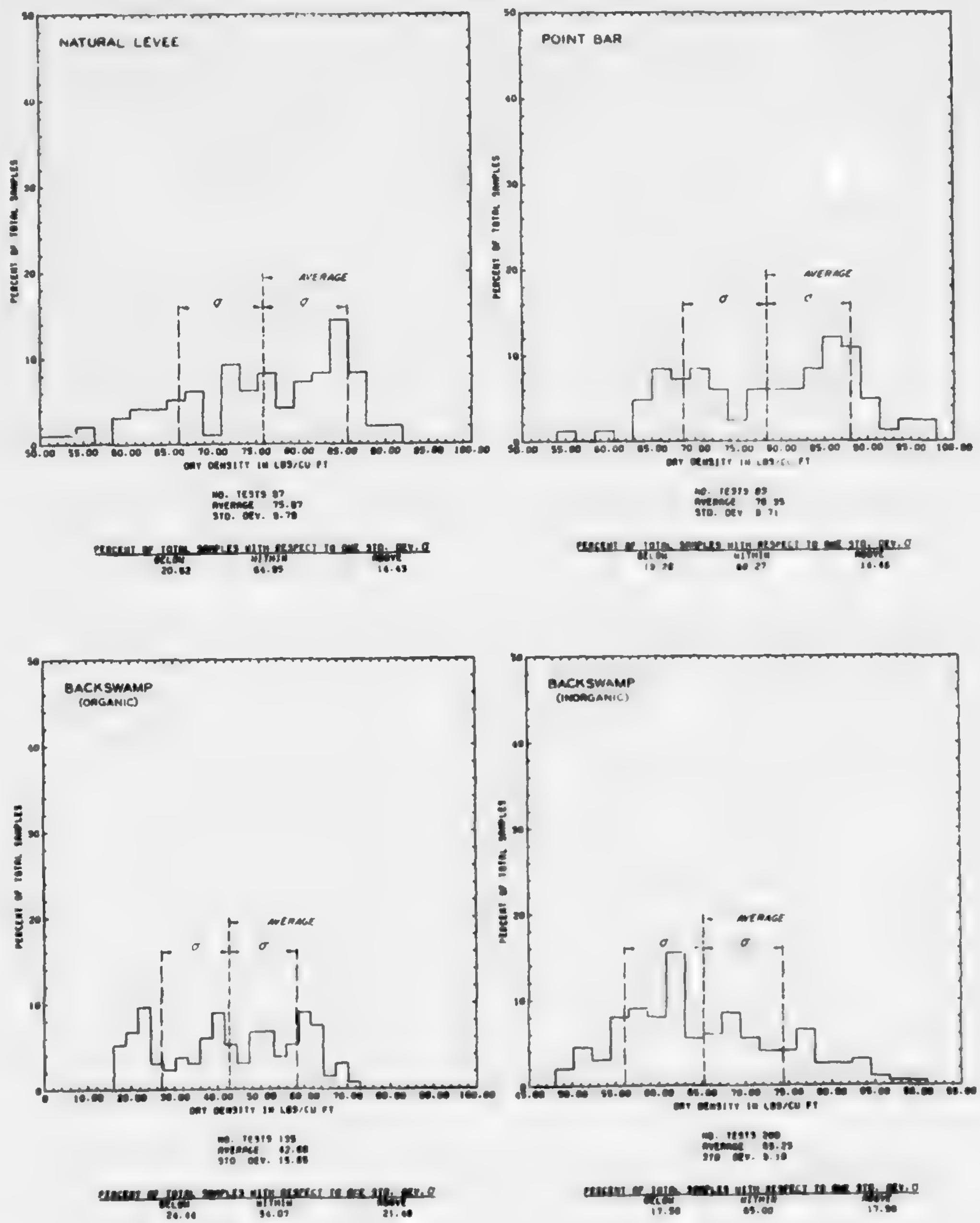

Fig. 2-10. Dry density frequency histograms for natural levee, point bar, and backswamp deposits

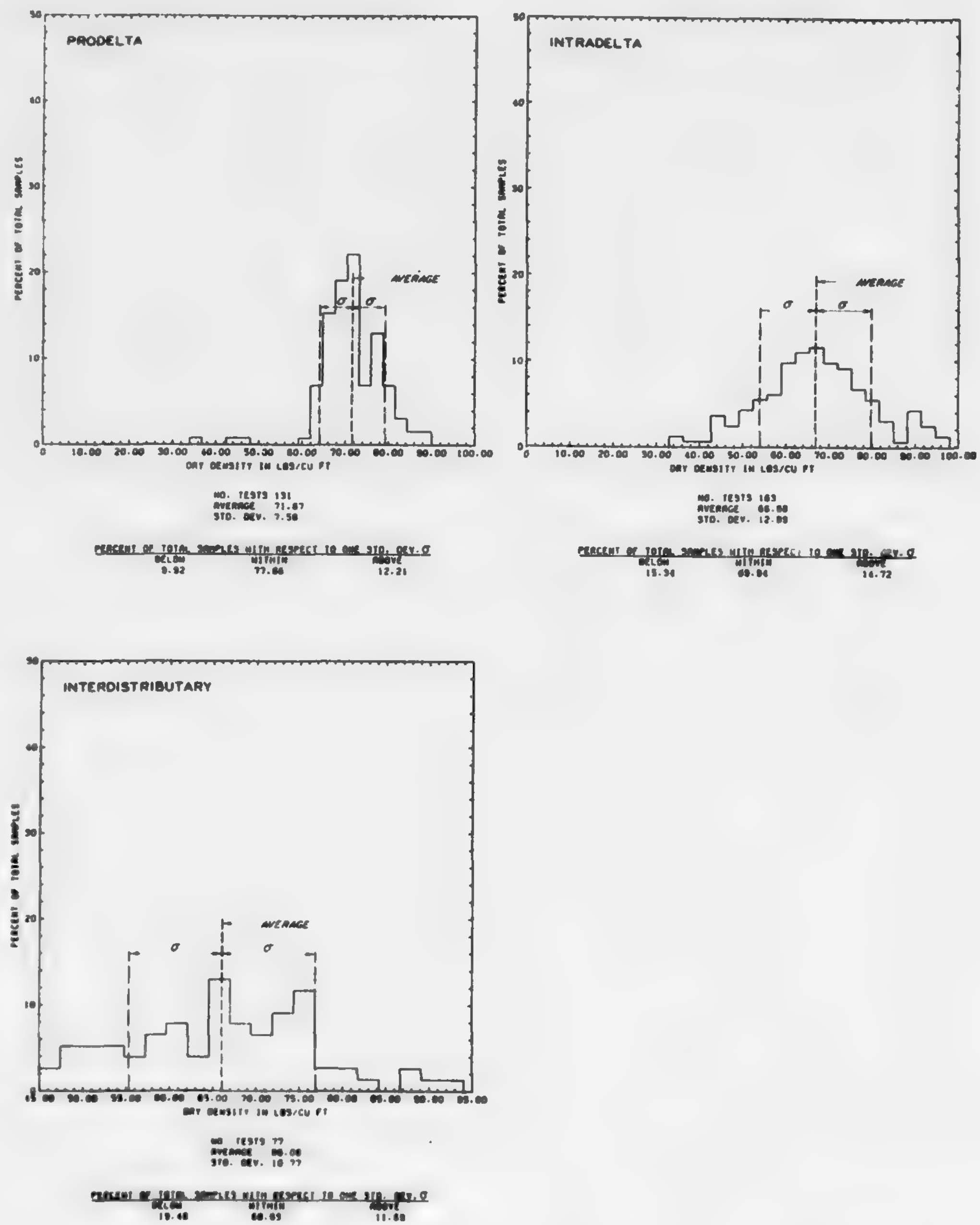

Fig. 2-11. Dry density frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-6

SUMMARY OF DRY DENSITY FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range pcf	Average pcf	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-10	97	50 - 92	75.9	9.8	65	Negative Skewness
Point Bar	2-10	83	54 - 98	78.3	9.7	66.3	Bimodal
Backswamp (Organic)	2-10	135	16 - 73	42.7	15.6	54	Multimodal
Backswamp (Inorganic)	2-10	200	48 - 91	65	9.2	65	Multimodal
Prodelta	2-11	139	49 - 90	72.3	7.6	77.8	Leptokurtic
Intradelta	2-11	163	33 - 98	66.9	12.9	66.9	Normal
Interdistributary	2-11	77	45 - 94	66	10.8	68.8	Multimodal

2.4.7 Specific Gravity

Frequency distributions of specific gravity are shown in figs. 2-12 and 2-13, and summarized in table 2-7.

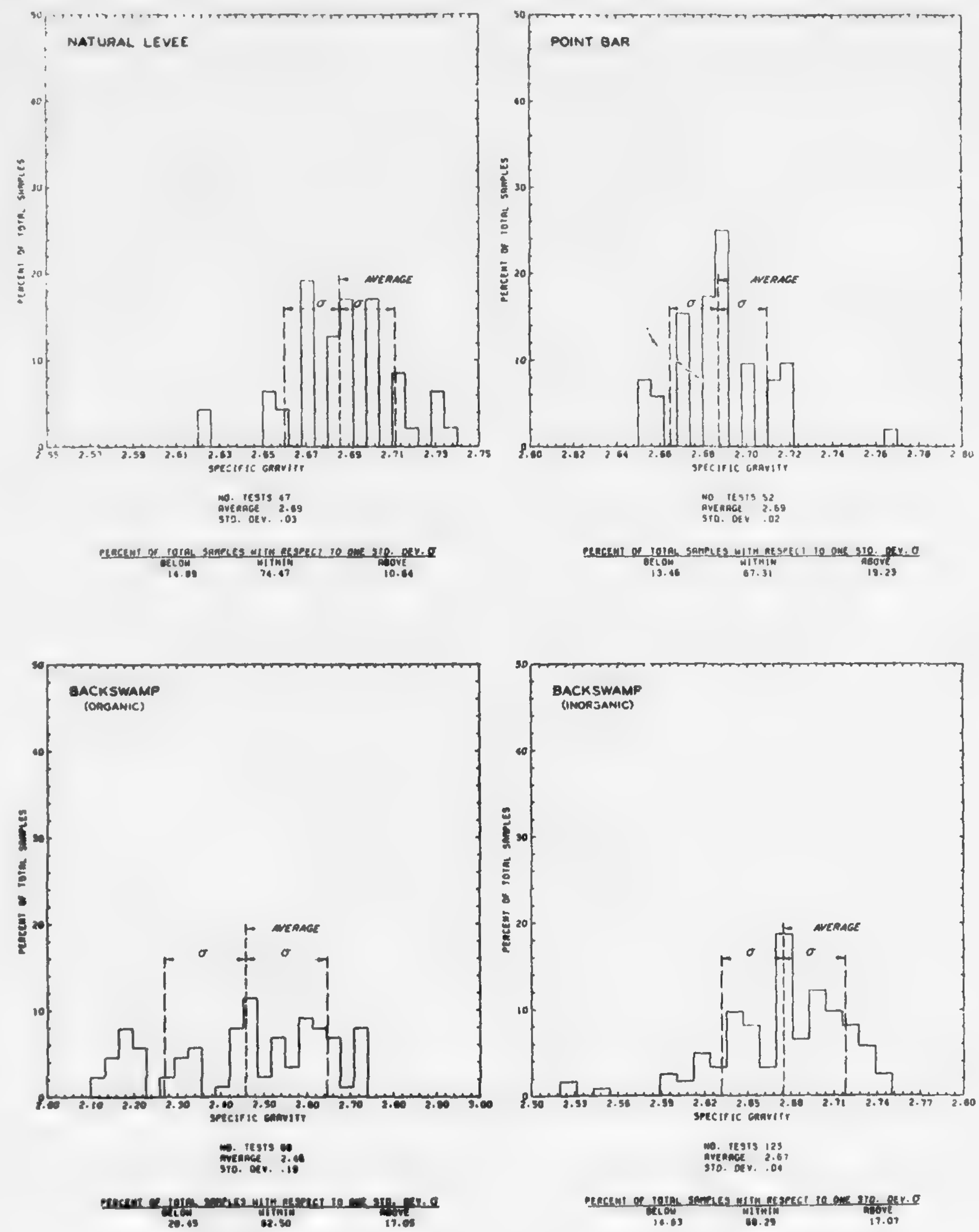

Fig. 2-12. Specific gravity frequency histograms for natural levee, point bar, and backswamp deposits

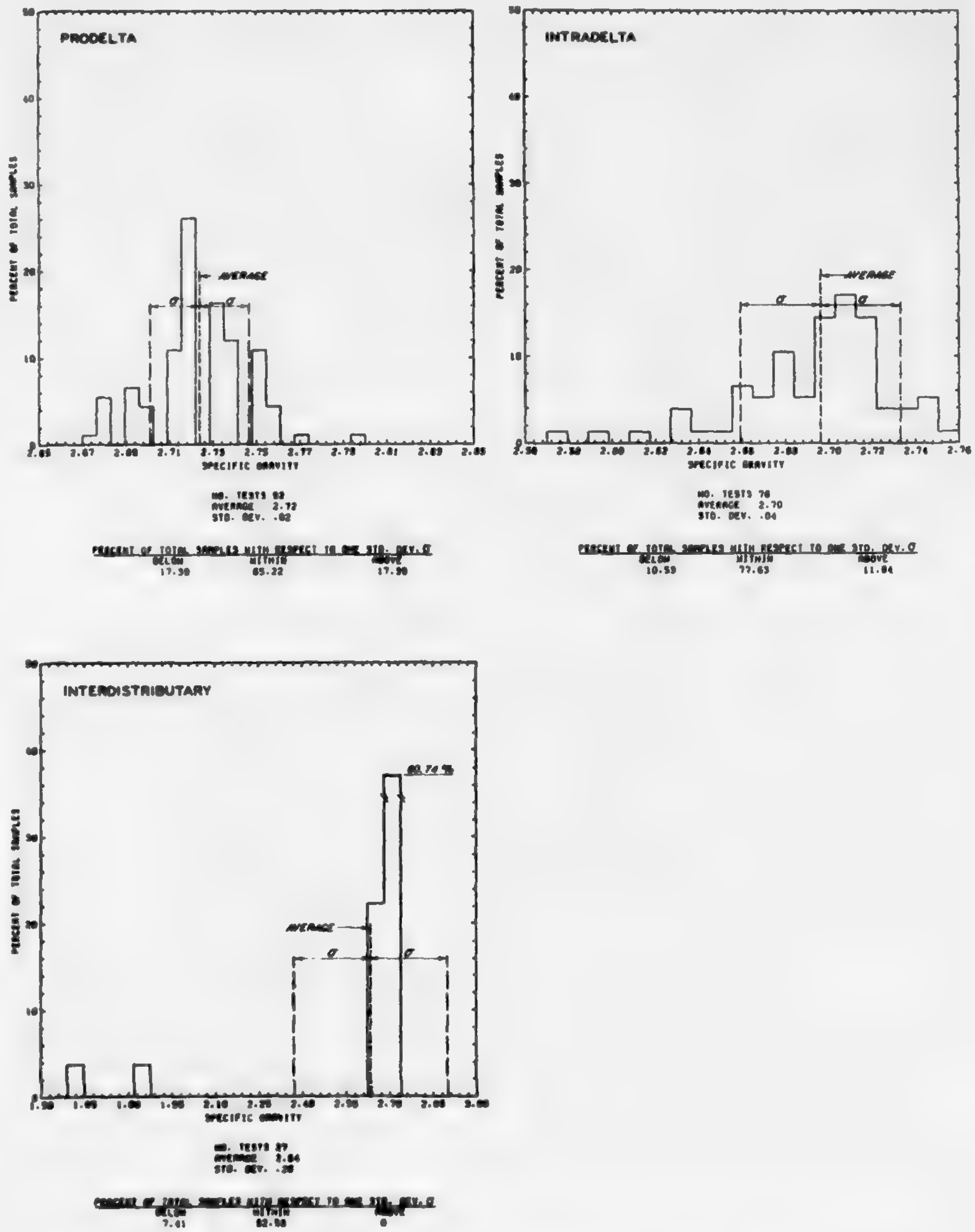

Fig. 2-13. Specific gravity frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-7

SUMMARY OF SPECIFIC GRAVITY FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range	Average	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-12	47	2.62 - 2.74	2.69	0.03	74.5	Multimodal
Point Bar	2-12	52	2.65 - 2.77	2.69	0.02	67.3	Multimodal
Backswamp (Organic)	2-12	88	2.10 - 2.74	2.46	0.19	62.5	Multimodal
Backswamp (Inorganic)	2-12	123	2.53 - 2.75	2.67	0.04	68.3	Multimodal
Prodelta	2-13	92	2.67 - 2.80	2.72	0.02	65.2	Normal
Intradelta	2-13	76	2.57 - 2.76	2.70	0.04	77.6	Negative Skewness
Interdistributary	2-13	27	1.59 - 2.74	2.64	0.26	92.6	Multimodal

2.4.8 Void Ratio

Frequency distributions of void ratio are shown in figs. 2-14 and 2-15, and summarized in table 2-8.

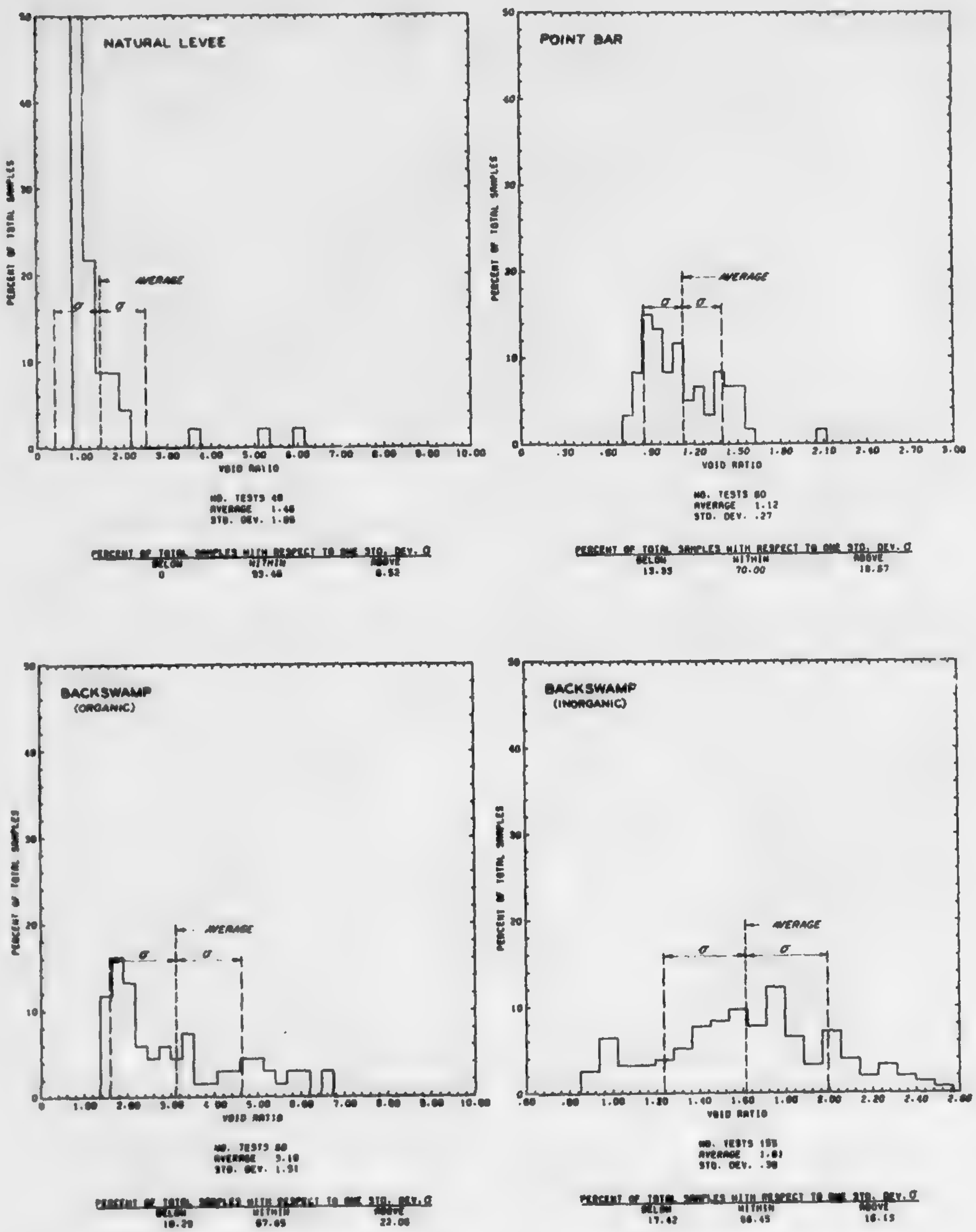

Fig. 2-14. Void ratio frequency histograms for natural levee, point bar, and backswamp deposits

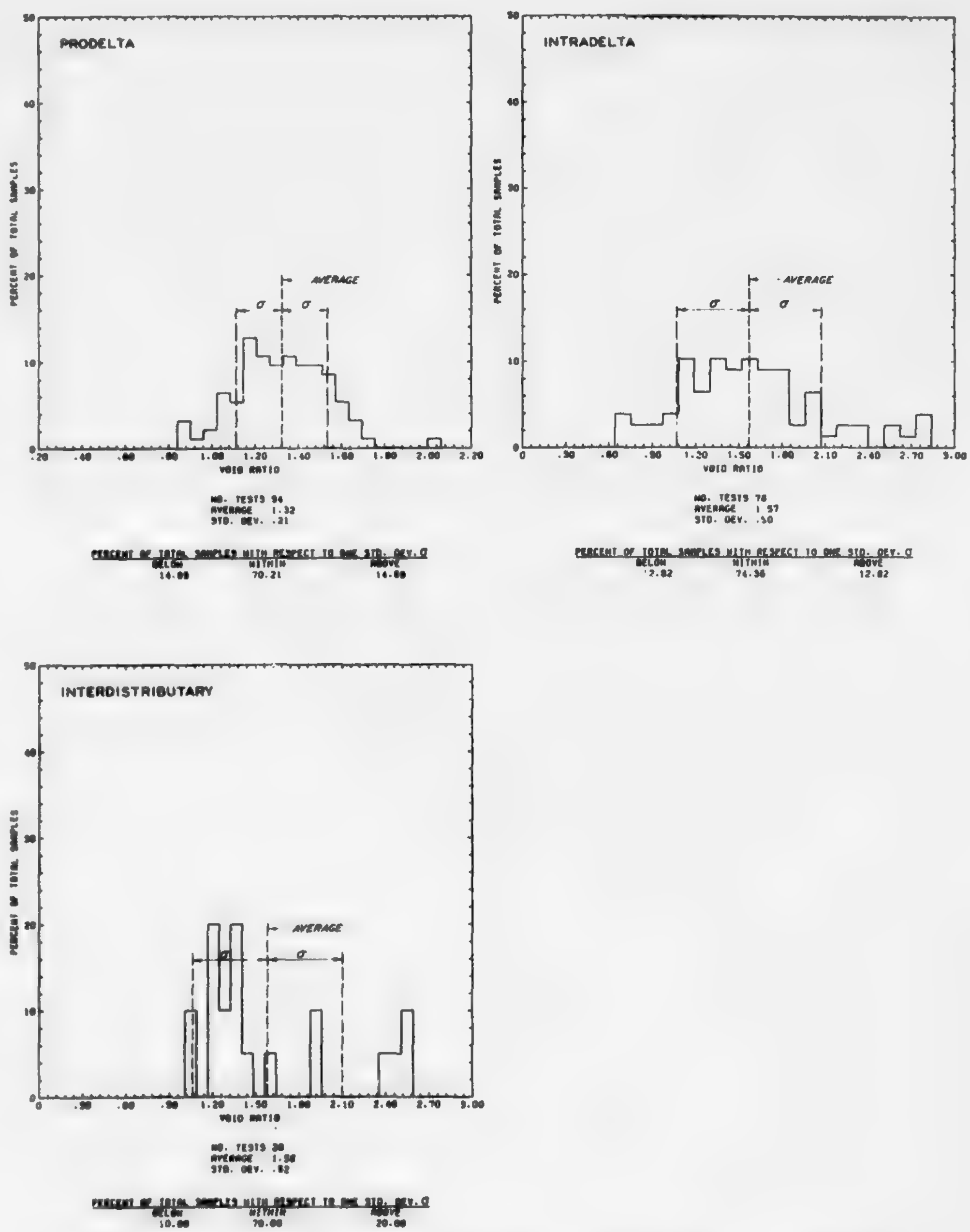

Fig. 2-15. Void ratio frequency histograms for prodelta, intradelta, and interdistributary deposits

TABLE 2-8

SUMMARY OF VOID RATIO FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range	Average	Standard Deviation	% Within Standard Deviation	Histogram Description
Natural Levee	2-14	46	0.82 - 6.16	1.46	1.05	93.5	Positive Skewness
Point Bar	2-14	60	0.70 - 2.12	1.12	0.27	70	Positive Skewness
Backswamp (Organic)	2-14	68	1.36 - 6.73	3.10	1.51	67.7	Positive Skewness
Backswamp (Inorganic)	2-14	155	0.85 - 2.57	1.61	0.38	66.5	Platykurtic
Prodelta	2-15	94	0.84 - 2.06	1.32	0.21	70.2	Normal
Intradelta	2-15	78	0.64 - 2.84	1.57	0.50	74.4	Normal
Interdistributary	2-15	20	1.01 - 2.59	1.58	0.52	70	Multimodal

2.4.9 s_u/p_o Ratio

The ratio between undrained shear strength (s_u) and effective overburden pressure p_o is known as the s_u/p_o ratio. Reference 8 suggests that a constant s_u/p_o ratio should exist for normally consolidated natural deposits. It has been found that a constant s_u/p_o ratio does exist for normally consolidated soils provided the plasticity index remains constant.[21] Correlation of s_u/p_o ratio with plasticity index will be discussed in later paragraphs. Frequency histograms of s_u/p_o ratio are presented in figs. 2-16 and 2-17. Histograms for the natural levee and organic backswamp deposits were omitted since these deposits are slightly overconsolidated. A summary of s_u/p_o data is provided in table 2-9.

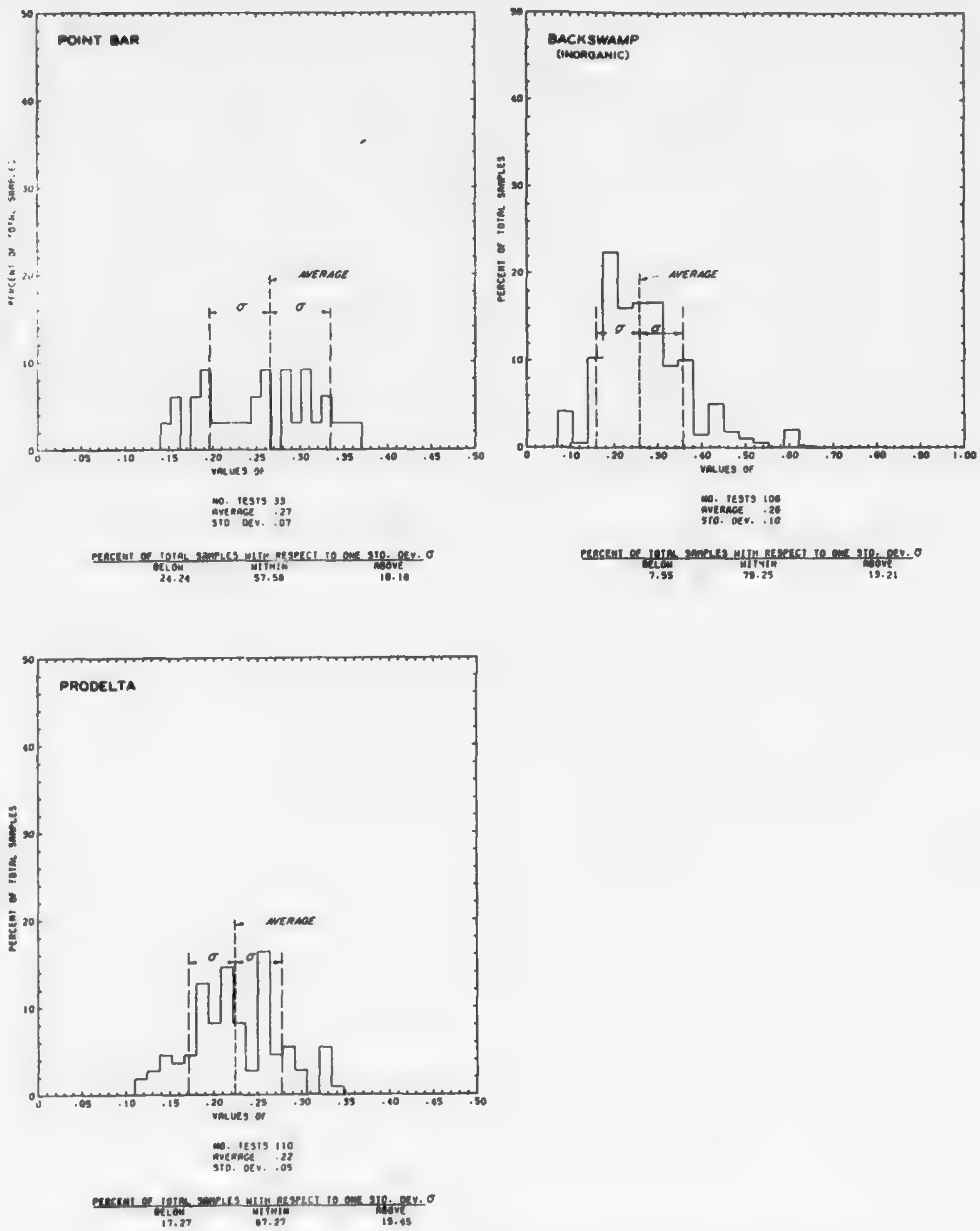

Fig. 2-16. s_u/p_o ratio frequency histograms for point bar, inorganic backswamp, and prodelta deposits

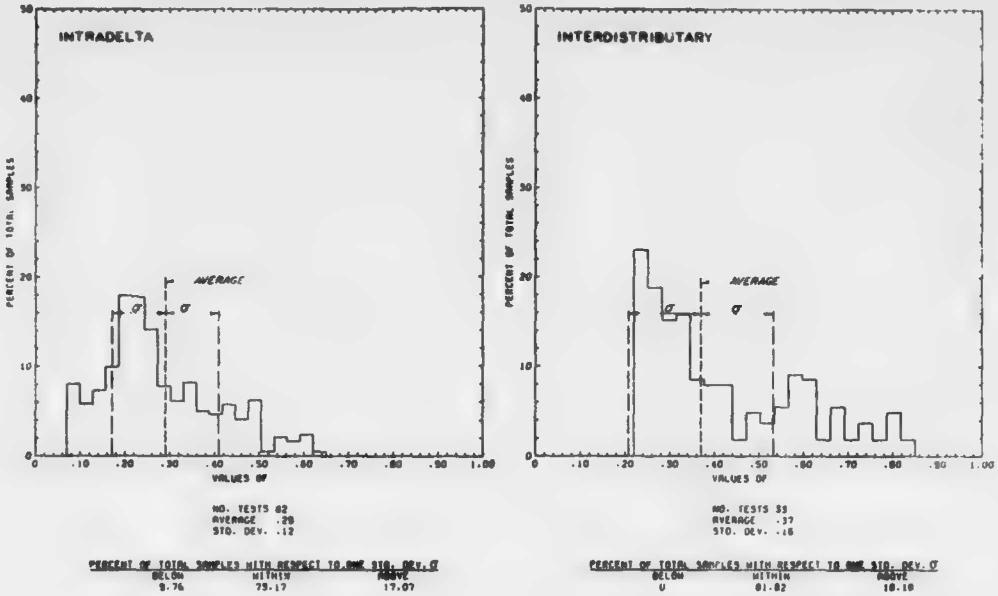

Fig. 2-17. s_u/p_o ratio frequency histograms for intradelta and interdistributary deposits

TABLE 2-9

SUMMARY OF s_u/p_o RATIO FREQUENCY HISTOGRAMS

Deposit	Figure	Number of Tests	Range	Average	Standard Deviation	% Within Standard Deviation	Histogram Description
Point Bar	2-16	33	0.14 - 0.37	0.27	0.07	57.6	Multimodal
Backswamp (Inorganic)	2-16	106	0.07 - 0.76	0.26	0.10	79.3	Leptokurtic
Prodelta	2-16	110	0.11 - 0.39	0.22	0.05	67.3	Multimodal
Intradelta	2-17	82	0.07 - 0.65	0.29	0.12	73.2	Positive Skewness
Interdistributary	2-17	33	0.22 - 0.85	0.37	0.16	81.8	Positive Skewness

2.4.10 Consolidated-Undrained Shear Strength

Consolidated-undrained shear (R) strengths are obtained from triaxial compression tests. Drainage of the test specimen is permitted and full primary consolidation is allowed to take place under the initially applied confining pressure. Drainage is stopped, and the axial stresses are increased until the specimen experiences shear failure. The R-shear strength is equal to the shear resistance of the specimen at the point of shear failure. The shear strength parameters from tests on a series of specimens at different confining pressures are described by both a friction angle and a cohesion value. The R-tests were consolidated under pressures of 1, 2, and 3 tons per sq ft. The shear strength parameters were obtained by a straight line approximation of the data. Frequency histograms for friction angles and cohesions are shown in figs. 2-18 and 2-19. Unfortunately, insufficient data were available to adequately analyze the R-shear strengths for the natural levee, point bar, prodelta, intradelta, and interdistributary deposits individually. The R-shear strengths for these deposits were analyzed collectively and called deltaic soils.

Deltaic. Based on 80 tests, the friction angle ranged between 8 and 22 degrees with an average of 13 degrees. The cohesion ranged between 0.01 and 0.50 ton per sq ft with an average of 0.20 ton per sq ft. The friction angle histogram in fig. 2-18 shows that the data are distributed relatively normal. The standard deviation of plus or minus 2.62 degrees from the average contains 65.2 percent of the data. The cohesion histogram in fig. 2-18 shows that the data are skewed to the

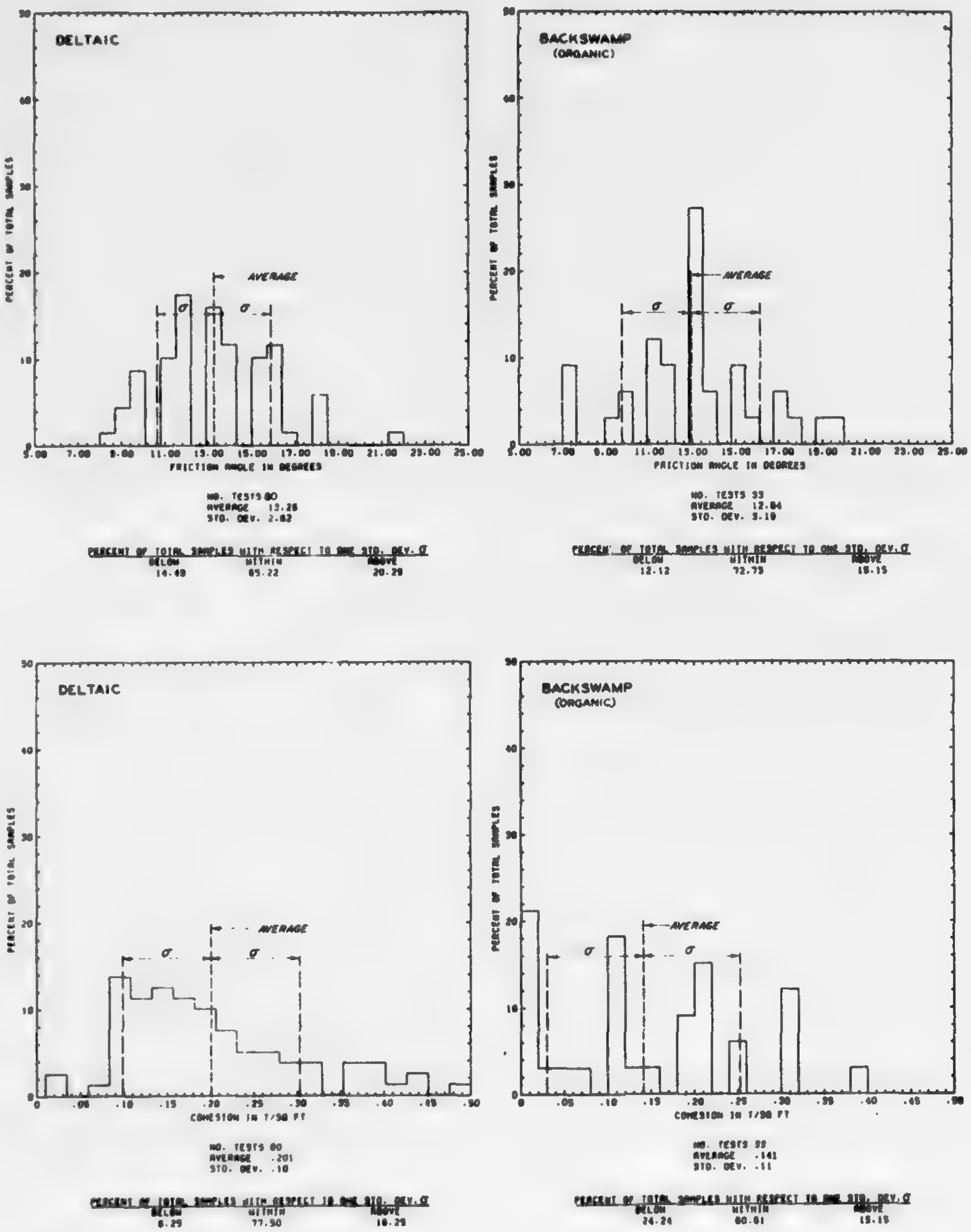

Fig. 2-18. R-test shear strength frequency histograms for deltaic and organic backswamp deposits

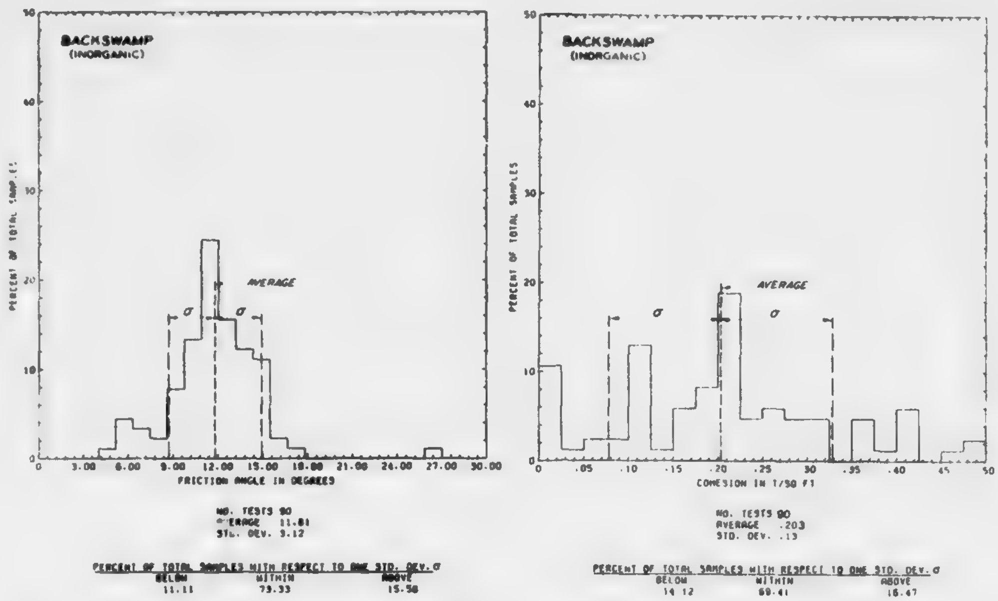

Fig. 2-19. R-test shear strength frequency histograms for inorganic backswamp deposits

right. The standard deviation of plus or minus 0.10 ton per sq ft from the average contains 77.5 percent of the data.

<u>Backswamp (organic).</u> Based on 33 tests, the friction angle ranged between 7 and 20 degrees with an average of 13 degrees. The cohesion ranged between 0 and 0.40 ton per sq ft with an average of 0.14 ton per sq ft. The friction angle histogram in fig. 2-18 shows that the distribution of data is multimodal. The standard deviation of plus or minus 3.2 degrees from the average contains 72.7 percent of the data. The cohesion histogram in fig. 2-18 shows that the standard deviation of plus or minus 0.11 ton per sq ft from the average contains 60.6 percent of the data. The data are distributed multimodally and are skewed to the right.

<u>Backswamp (inorganic).</u> Based on 90 tests, the friction angle

ranged between 4 and 27 degrees with an average of 12 degrees. The cohesion ranged between 0 and 0.50 ton per sq ft with an average of 0.20 ton per sq ft. The friction angle histogram in fig. 2-19 shows that the data are normally distributed with a leptokurtic shape. The standard deviation of plus or minus 3.1 degrees from the average contains 73.3 percent of the data. The cohesion histogram in fig. 2-19 shows that the data are multimodally distributed. The standard deviation of plus or minus 0.13 ton per sq ft from the average contains 69.4 percent of the data.

2.4.11 Drained Shear Strength

Drained shear strength is normally obtained by means of the S-test performed in either direct shear apparatus or triaxial apparatus.[7] The drained shear strengths presented herein were obtained from S-tests using the direct shear apparatus. The term "direct shear" is used because failure is induced on a specific plane on which the normal and shear stresses at failure are known. The shear strength parameters from the direct shear strength test are designated as the angle of internal friction ϕ' and cohesion c'. These parameters are affected significantly by the amount of preconsolidation pressure to which the samples have been subjected; therefore, care was taken to separate the data based on consolidation test data. Insufficient drained strength data were available for the natural levee, point bar, prodelta, intradelta, and interdistributary deposits to adequately present them individually. The drained shear strengths for these soils

were combined and presented as deltaic soils. The data presented in fig. 2-20 include deltaic, organic backswamp, and inorganic backswamp deposits. The data presented for the deltaic deposits are from tests on reasonably normally consolidated soils; the organic backswamp deposits are considered slightly overconsolidated; and the inorganic backswamp deposits are reasonably normally consolidated.

Deltaic. Based on 22 tests the friction angle ranged between 16 and 31 degrees with an average of 23.7 degrees. The histogram in fig. 2-20 shows that the data are distributed in a multimodal shape. The standard deviation of plus or minus 4.86 degrees from the average contains 63.6 percent of the data. Cohesion values ranged between 0 and 0.16 ton per sq ft but were not presented in histogram form.

Backswamp (organic). Based on 25 tests, the friction angle ranged between 13 and 35 degrees with an average of 22 degrees. The histogram in fig. 2-20 shows that the data are distributed in a multimodal shape. However, it is reasonably good presentation of data. The standard deviation of plus or minus 5.23 degrees from the average contains 72 percent of the data. Cohesion values ranged between 0 and 0.15 ton per sq ft but were not presented in histogram form.

Backswamp (inorganic). Based on 86 tests the friction angle ranged between 12 and 36 degrees and averages 20.6 degrees. Based on the histogram shown in fig. 2-20, the data are distributed in a reasonably normal shape, but the kurtosis is leptokurtic. The standard deviation of plus or minus 3.48 degrees from the average contains 75.6 percent of the data. Cohesion values ranged between 0 and 0.30 ton per sq ft but were not presented in histogram form.

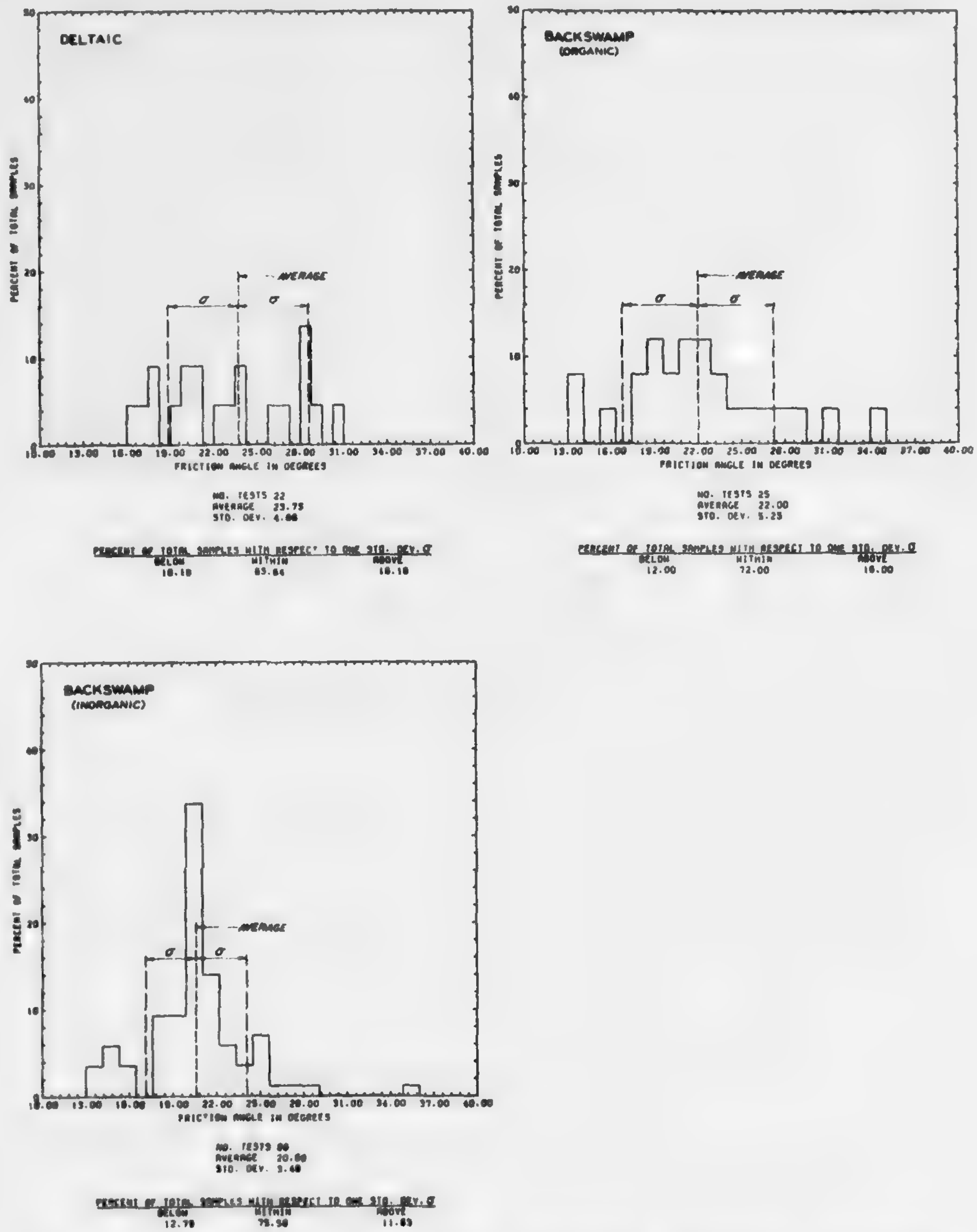

Fig. 2-20. S-test shear strength frequency histograms for deltaic and backswamp deposits

CHAPTER III

ENGINEERING PROPERTIES OF SOIL AS A FUNCTION OF DEPTH

If it can be established that in fact, the distribution of pertinent soil properties of fluvial and fluvial-marine deposits do vary systematically with depth, this knowledge can be of great value in engineering design problems. The number of laboratory tests to establish soil properties of these deposits could be greatly reduced, and the results of these tests could be applied to permit designs with greater confidence. Generally, it is desirable to know whether any relationship between natural water content and plasticity characteristics with depth can be established. If so, the shear and consolidation characteristics of the soil then can be determined by correlations such as those described in later paragraphs. Studies were made to determine not only the distribution of natural water content and Atterberg limits but also the distribution of preconsolidation pressures and undrained shear strength with depth. The preconsolidation pressures and effective overburden pressures are discussed previously in Chapter II. The undrained shear strengths included in this study were determined from unconsolidated-undrained triaxial compression Q-tests (also called quick, undrained, or UU test).

3.1 Natural Levee Deposits

3.1.1 Natural Water Contents and Atterberg Limits

The range of natural water contents and plastic range are shown in fig. 3-1. It should be noted that the plastic range is based on the

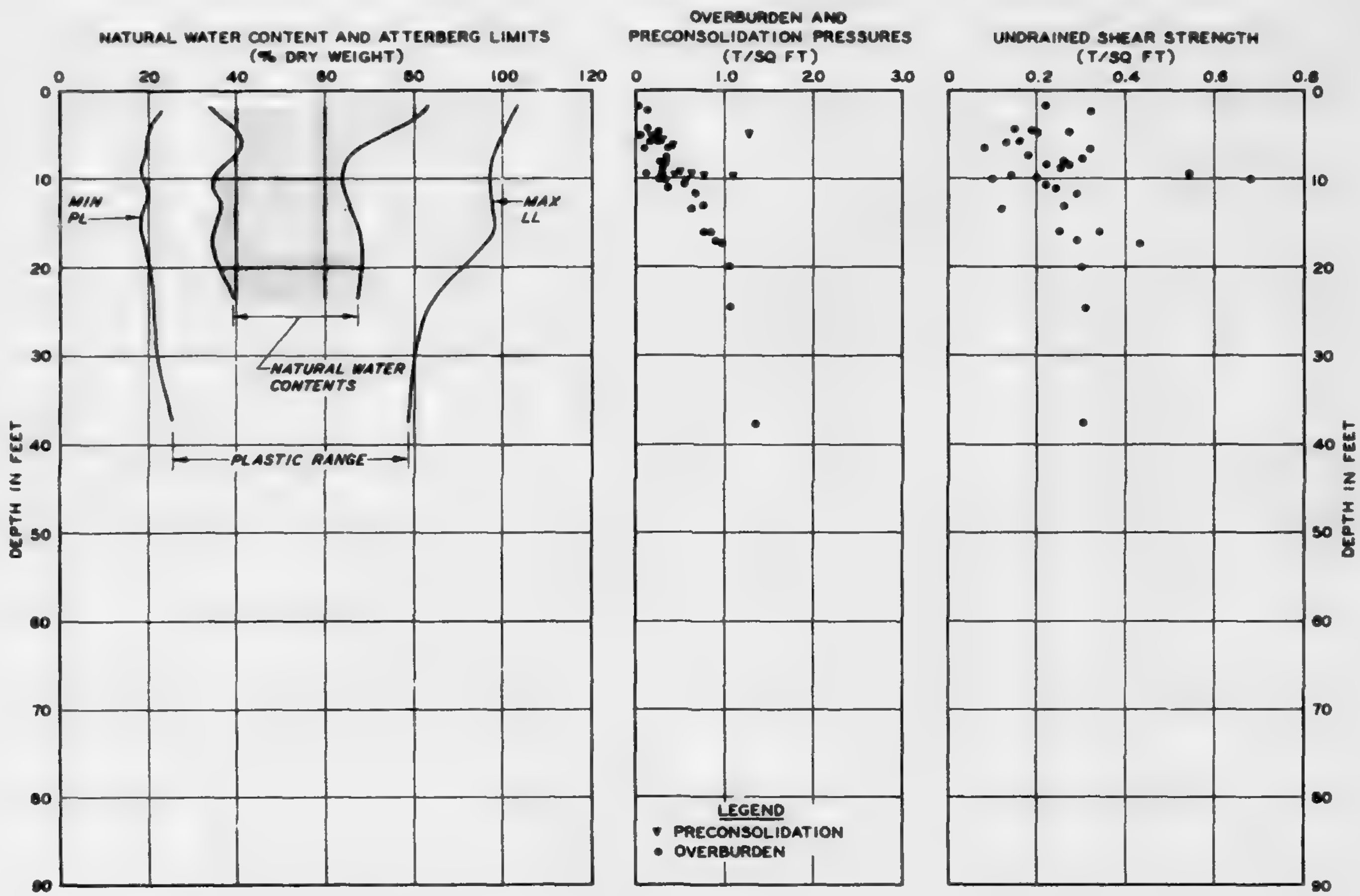

Fig. 3-1. Soil properties versus depth for natural levee deposits

minimum values of plastic limit and maximum values of liquid limit based on numerous data. This range does not necessarily correspond to plasticity index. The plastic range appears to decrease slightly with depth. The natural water contents are basically concentrated near the center of the plastic range.

3.1.2 Overburden and Preconsolidation Pressures

Based on the data shown in fig. 3-1 the preconsolidation pressures generally exceed the computed effective overburden pressures, thus indicating an overconsolidated soil. There is an appreciable amount of scatter in the data for the overburden pressures. These soils have not experienced overburden pressures greater than those imposed by the existing overburden, and any excessive preconsolidation exhibited by them is caused solely by desiccation either during or after their deposition.

3.1.3 Undrained Shear Strength

The undrained shear strengths plotted against depth, as shown in fig. 3-1, do not exhibit an increasing trend with depth. In fact, there is no correlation with depth. The data exhibit a rather random pattern down to about a depth of 10 ft. Below that there is a slight indication of a trend. The slightly overconsolidated nature of this deposit is a reasonable explanation for the random pattern of data.

3.2 Point Bar Deposits

3.2.1 Natural Water Contents and Atterberg Limits

The natural water contents and plastic range are shown in fig. 3-2 plotted versus depth. Based on this plot, the plastic range for point

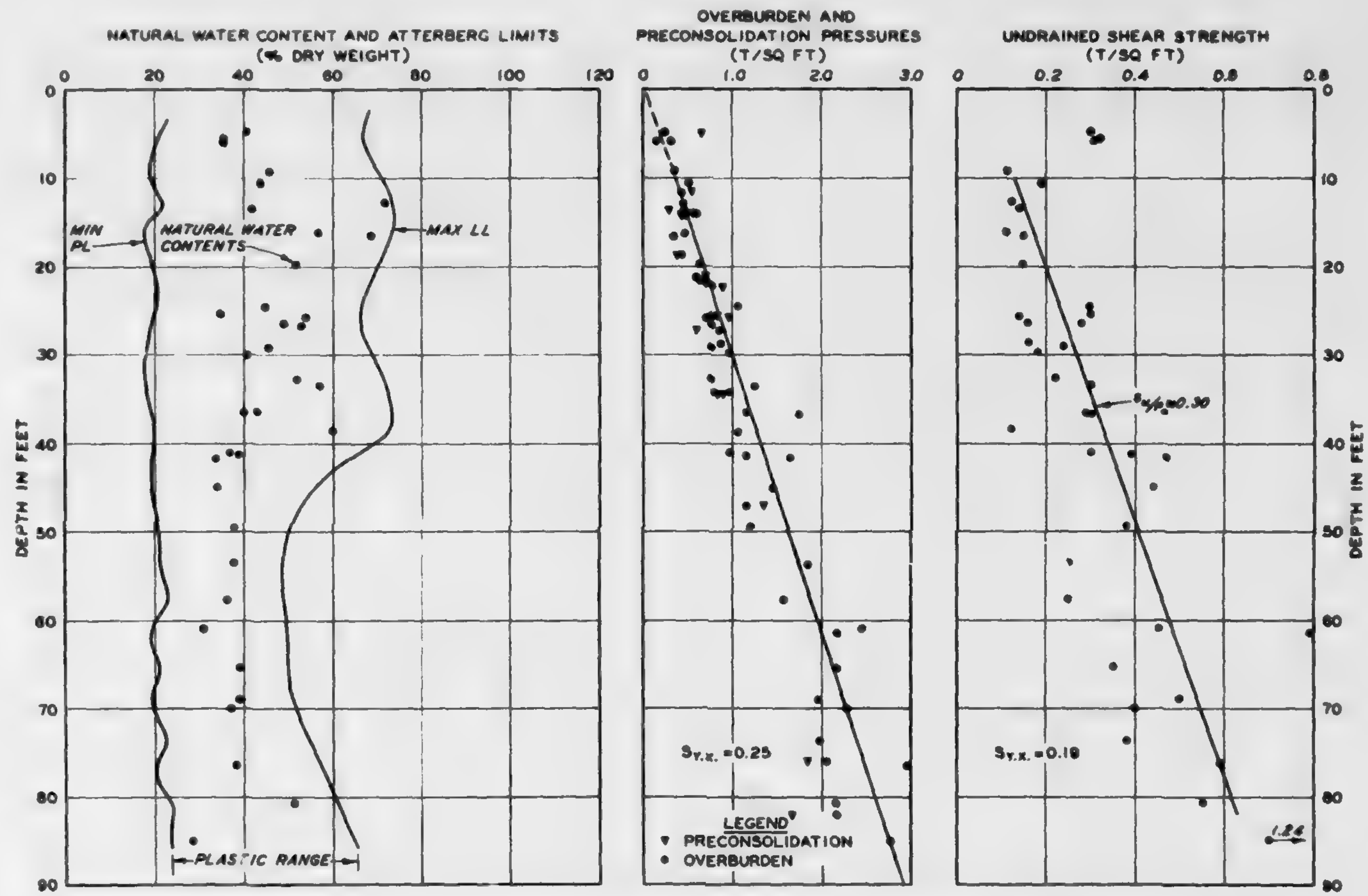

Fig. 3-2. Soil properties versus depth for point bar deposits

bar deposits appears to narrow with depth. The data were insufficient to establish a range of natural water contents within the plastic range for this deposit. Thus the natural water contents are plotted individually. They generally plot nearer the upper limit of the plastic range above a depth of about 40 ft; below that depth, they are located nearer the center of the plastic range. The lower limit (plastic limit) of the plastic range is relatively constant with depth while the upper limit (liquid limit) decreases with depth. Fig. 3-2 shows that the silty point bar deposits exhibit an appreciable decrease in plasticity below a depth of about 40 ft.

3.2.2 Overburden and Preconsolidation Pressures

Effective overburden and preconsolidation pressures are plotted versus depth in fig. 3-2. The effective overburden pressures (p_o) are represented by a best-fit straight line located by the method of least squares. The method of least squares is discussed in more detail in Chapter IV. Below a depth of ten feet, the relation between effective overburden pressure and depth can be expressed by a linear line of regression. The preconsolidation pressures lie very close to the regression line in fig. 3-2. Based on these data, the point bar soils included in this study can be considered to be normally consolidated.

3.2.3 Undrained Shear Strength

The undrained shear strength values plotted versus depth in fig. 3-2 show an increasing trend with depth. The trend of the change in undrained shear strength (s_u) with depth can be represented by a linear line of regression. The standard deviation from regression is 0.19 unit of s_u. This line of regression represents the trend of s_u

below a depth of 10 ft; above that depth, the s_u showed no trend with depth. Based on the data shown in fig. 3-2, the s_u ranges between 0.11 and 1.24 ton per sq ft. The s_u increased with effective overburden pressure according to the relation defined by the ratio $s_u/p_o \approx 0.30$. This ratio is also known as the shear strength increase factor. The higher shearing strength in the upper 10 ft is associated with a slight overconsolidation effect resulting from desiccation. There is appreciable scatter in the strength data which could indicate that the sediments are still undergoing primary consolidation or could represent anomalies that occurred during testing. Although the trends developed in fig. 3-2 appear reasonable, the writer feels that insufficient data were available to fully analyze the undrained shear strengths of silty point bar deposits. Use of this data should be restricted to making rough estimates and as supplemental data for preliminary designs.

3.3 Backswamp Deposits

Fig. 3-3 includes data from both organic and inorganic backswamp deposits. A composite presentation of the properties of backswamp deposits was considered to be more indicative of natural conditions.

3.3.1 Natural Water Contents and Atterberg Limits

Fig. 3-3 shows that the natural range of water contents and the plastic range vary considerably down to a depth of about 30 ft. The soils within these ranges are slightly organic to highly organic. Below 30 ft, the plastic range is reasonably constant and natural water contents appear to have a decreasing trend approaching the lower limit of the plastic range.

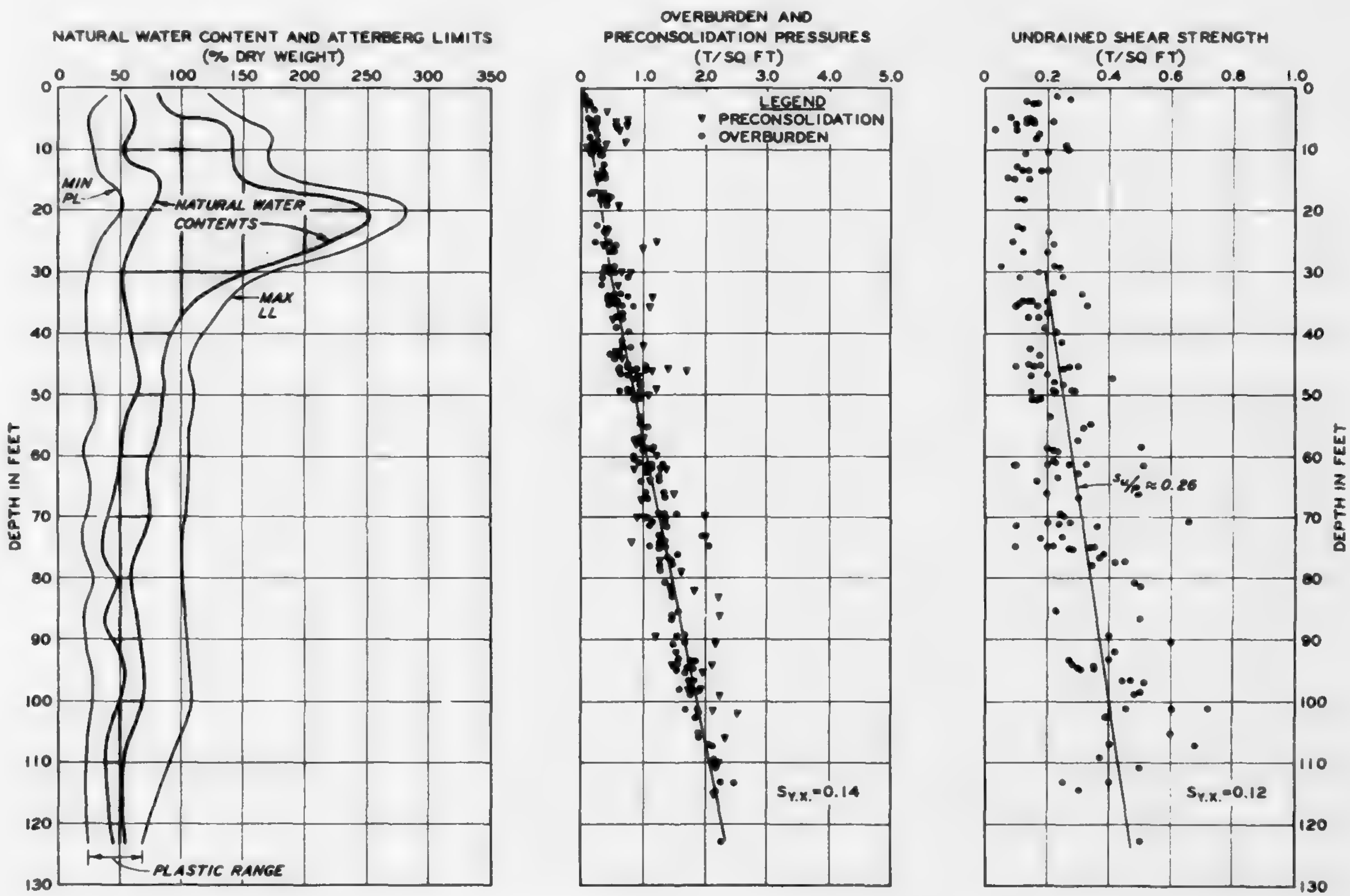

Fig. 3-3. Soil properties versus depth for backswamp deposits

3.3.2 Overburden and Preconsolidation Pressures

The effective overburden and preconsolidation pressures are plotted versus depth in fig. 3-3. A linear relationship exists between p_o and depth, below a 30-ft depth. The preconsolidation pressures (p_c) plot on both sides of the line of best-fit for the data, thus indicating that the backswamp deposits consist of underconsolidated, normally consolidated, and overconsolidated soils. Overconsolidation is much more prevalent in the upper more organic portion of the deposits.

3.3.3 Undrained Shear Strength

The undrained shear strengths are plotted versus depth in fig. 3-3. Below a depth of about 30 ft the strength increase is reasonably constant with depth and the trend can be represented by a linear line of regression. The standard deviation from the regression line is 0.12 unit of s_u. The shear strength data between 0- and 30-ft depth were omitted. Based on the data shown in fig. 3-3 the s_u range between 0.03 and 0.27 ton per sq ft for the organic soils and 0.10 and 0.72 ton per sq ft for the inorganic soils. The shear strength increase factor for the inorganic backswamp soils is expressed by $s_u/p_o \approx 0.26$. These soils have never experienced overburden pressures greater than those existing at the time of this study. The overconsolidation of soils in the upper portions of the deposits and the slight overconsolidation of soils in the lower portions can be associated with desiccation during and after deposition.

3.4 Prodelta Deposits

It was pointed out earlier in this study that the prodelta deposits

are the most homogeneous of the deltaic deposits. This fact is exemplified clearly by the data plotted in fig. 3-4.

3.4.1 Natural Water Contents and Atterberg Limits

The natural water content range and the plastic range are reasonably constant with depth. Although the natural water contents seem to have a slight trend toward the lower limit of the plastic range with depth. The range of natural water contents at all depths is closer to the lower limit of the plastic range.

3.4.2 Overburden and Preconsolidation Pressures

The overburden and preconsolidation pressures are plotted versus depth in fig. 3-4. The overburden pressures can be represented by a straight line. The preconsolidation pressures lie reasonably close to the overburden pressures, indicating that the prodelta deposits are normally consolidated.

3.4.3 Undrained Shear Strength

The plot of undrained shear strengths versus depth in fig. 3-4 shows an increasing trend with depth. The strengths range between 0.18 and 0.85 ton per sq ft. The standard deviation from the regression line is 0.09 unit of s_u. The shear strength increase factor is expressed as $s_u/p_o \approx 0.22$.

3.5 Intradelta Deposits

3.5.1 Natural Water Contents and Atterberg Limits

The natural water content range and plastic range are shown versus depth in fig. 3-5. Both these ranges appear to decrease with depth. The lower limit of the plastic range is reasonably constant

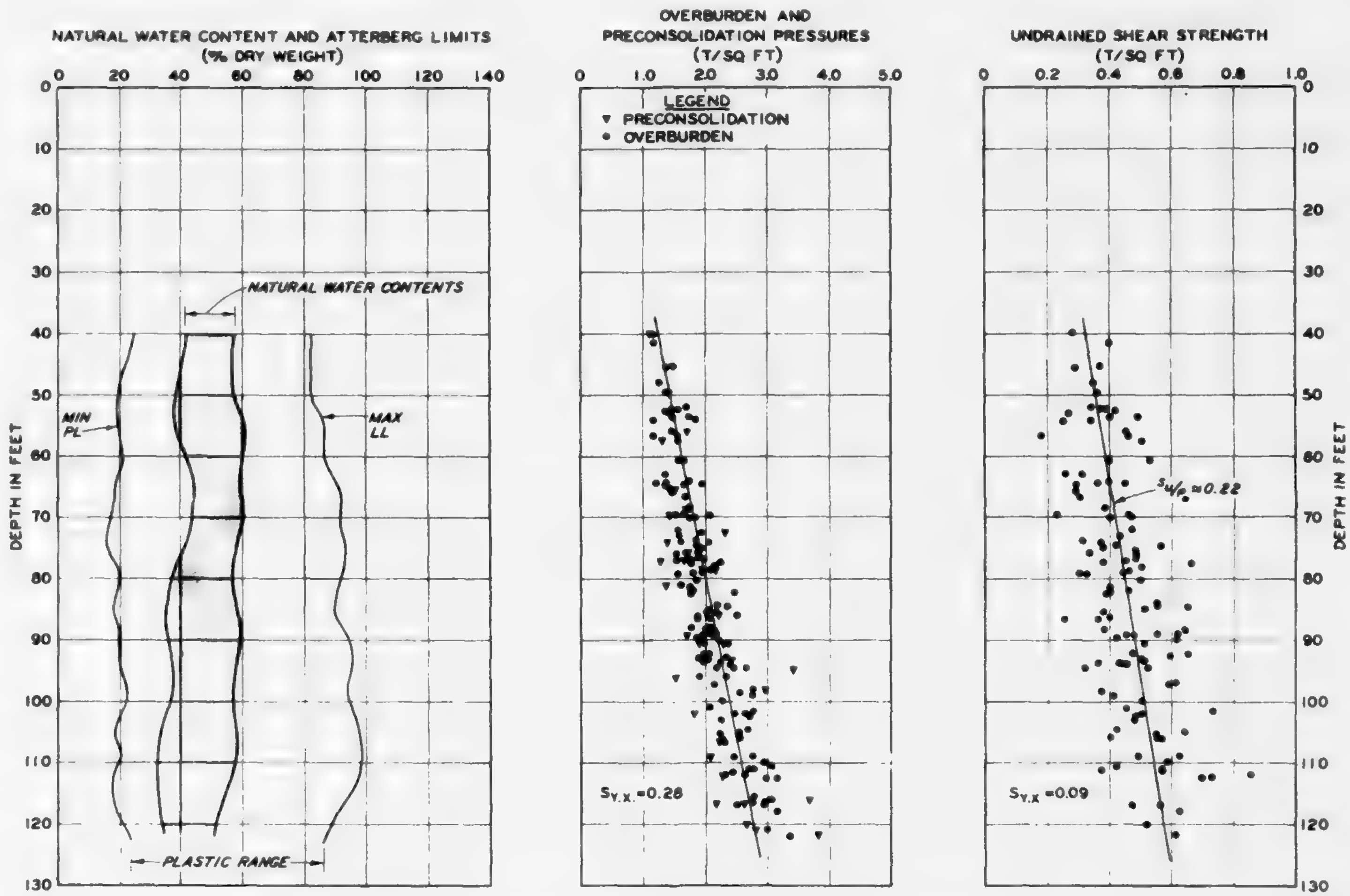

Fig. 3-4. Soil properties versus depth, prodelta deposits

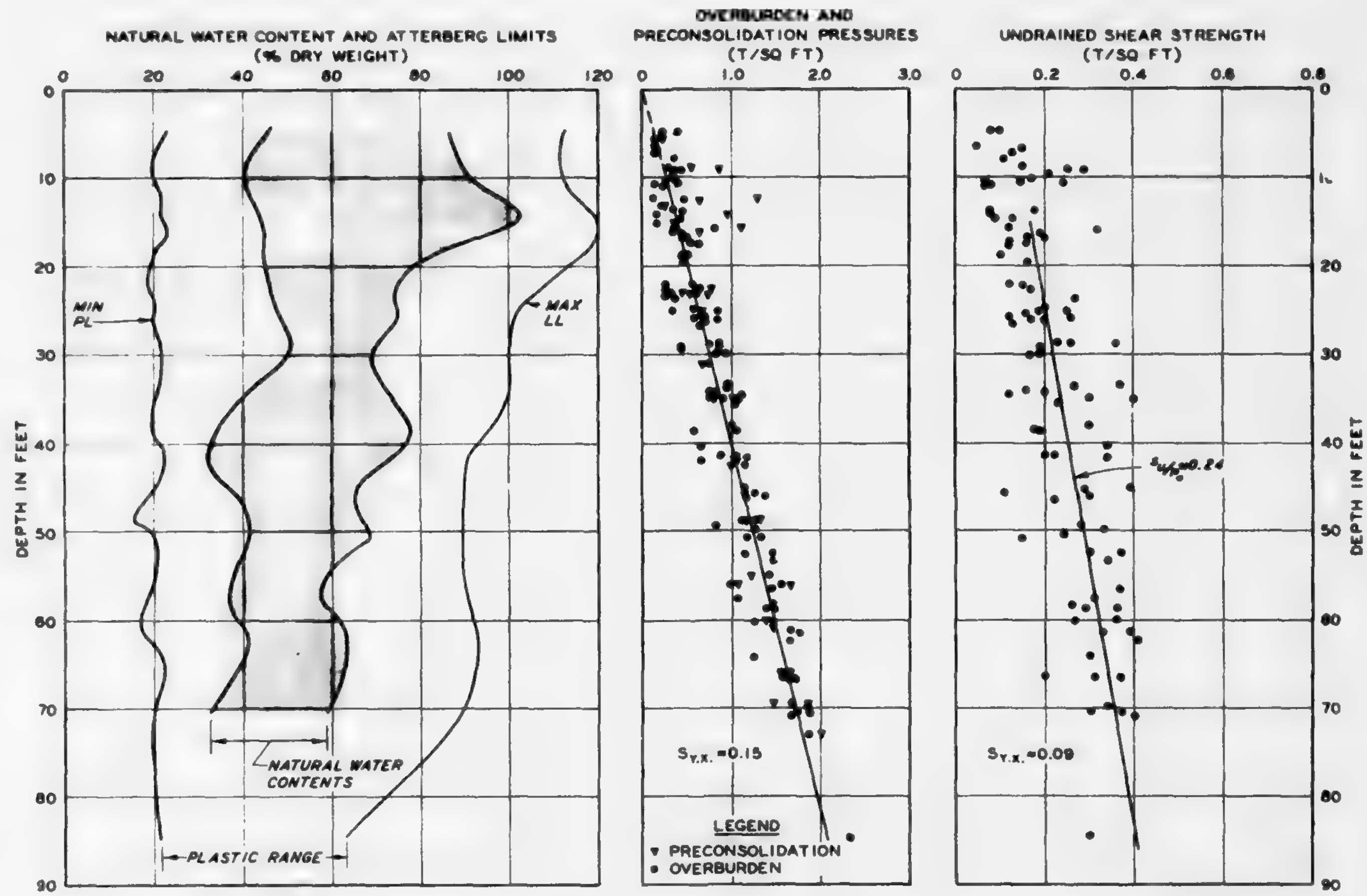

Fig. 3-5. Soil properties versus depth for intradelta deposits

with depth. Natural water contents appear to be confined to the middle of the plastic range. A highly plastic range is noted between the 10-15 ft depths. This can be attributed to the presence of organic materials.

3.5.2 Overburden and Preconsolidation Pressures

The overburden and preconsolidation pressures are plotted versus depth in fig. 3-5. Preconsolidation pressures agree reasonably well with overburden pressures, with the exception occurring between depths of 10 and 15 ft where preconsolidation pressures are appreciably larger, thus indicating a range of overconsolidated soils. At other depths, the soils appear to be normally consolidated.

3.5.3 Undrained Shear Strength

Undrained shear strengths are plotted versus depth in fig. 3-5. The strengths increase with depth, below 15 ft depth. The standard deviation from the regression line is 0.09 unit of s_u. The shear strength increase factor is represented by $s_u/p_o \approx 0.24$. The strengths range between 0.05 and 0.40 ton per sq ft.

3.6 Interdistributary Deposits

3.6.1 Natural Water Contents and Atterberg Limits

The plastic range shown in fig. 3-6 is slightly erratic in regard to its upper limit. The lower limit remains reasonably constant with depth. Insufficient data were available to establish a range of natural water contents with depth; thus, the individual data are shown. The writer feels that there were insufficient data available to permit conclusive analyses.

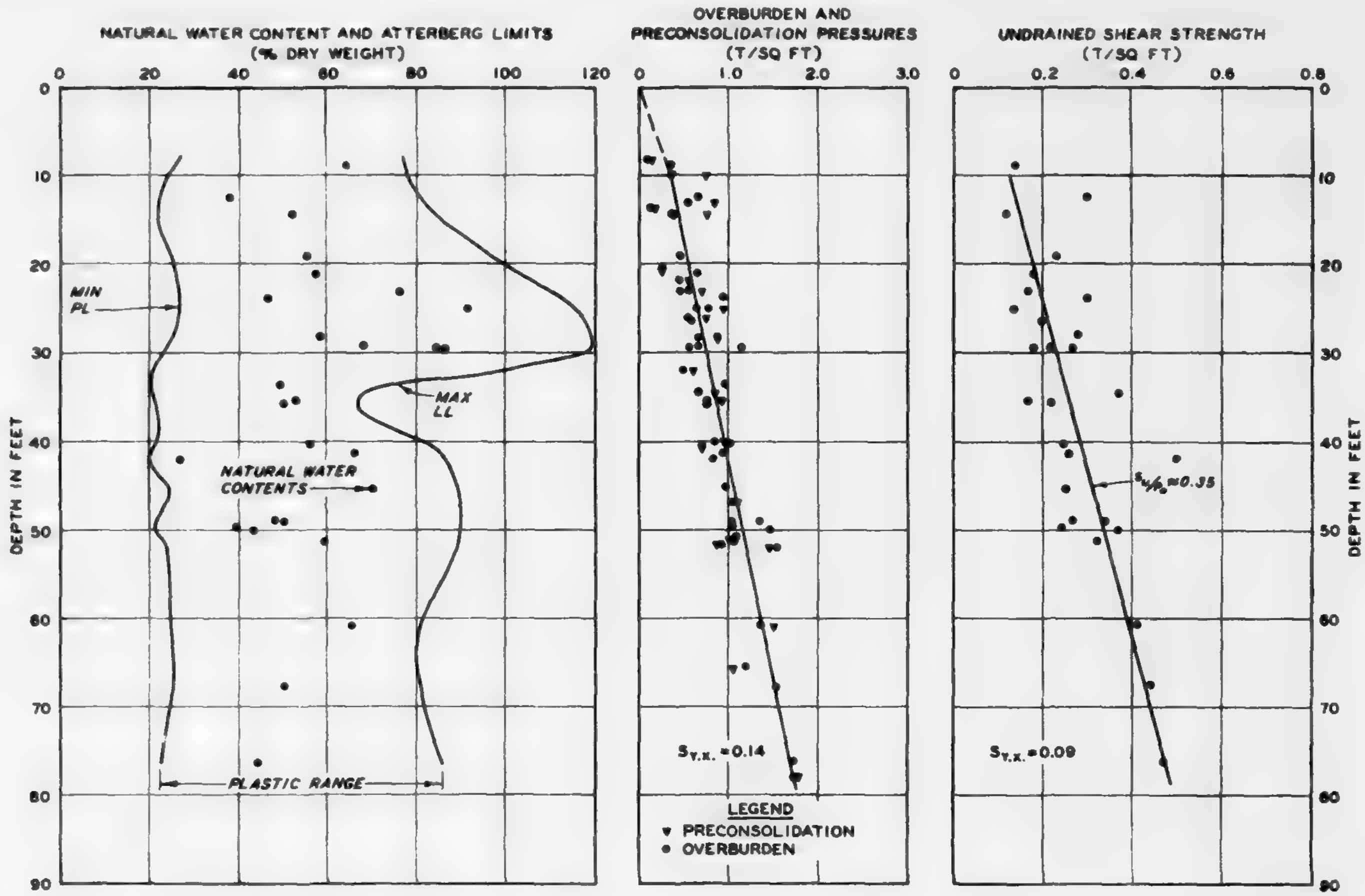

Fig. 3-6. Soil properties versus depth for interdistributary deposits

3.6.2 Overburden and Preconsolidation Pressures

In fig. 3-6, the effective overburden and preconsolidation pressures are plotted versus depth. The preconsolidation pressures determined from laboratory consolidation tests agree closely with the computed overburden pressures, indicating that the interdistributary deposits analyzed herein are normally consolidated.

3.6.3 Undrained Shear Strength

The undrained shear strengths plotted versus depth in fig. 3-6 show an increasing trend with depth. This trend can be represented by a straight line. The standard deviation from the regression line is 0.09 unit of s_u. The strength increase factor is indicated by $s_u/p_o \approx 0.35$. The strengths ranged between 0.12 and 0.50 ton per sq ft.

CHAPTER IV

CORRELATION OF SOIL PROPERTIES

Man has used soil as a construction material since the beginning of civilization, although its employment as such is more hazardous than the use of any other construction material. More money is spent on earthwork construction than on any other type of construction and the failures of such construction cause a greater loss of life and property than the failure of any other construction. This is true today, even though such men as Terzaghi, Casagrande, and others have contributed much knowledge toward better understanding the properties of soils and the interaction of soil properties. Because of the heterogeneous nature and characteristics of soils, the design engineer must have more knowledge and a better understanding of the fundamental properties of soils than of other construction materials. Correlations to identify the relationships between soil properties can frequently be of significant help to the design engineer. Correlations permit the design engineer to make preliminary estimates and designs based on a minimum of soils data with more assurance. Investigations by Sherman and Hadjidakis[18] showed that there are reliable correlations between soil properties in the meander belt and backswamp deposits of the Mississippi River alluvial plain. McClelland[19] reported correlations for the prodelta clays of the Mississippi River deltaic plain that were encountered on the continental shelf in the Gulf of Mexico. Correlations have been found to exist between index properties (determined from simple and relatively inexpensive laboratory tests) and shear and consolidation properties

(which must be determined from more complex and costly laboratory tests). Such correlations are of great value to an engineer for use in the design of minor projects where economy does not warrant extensive laboratory testing. Correlations also make possible a significant reduction in the amount of laboratory testing required on all projects. In general, correlations contribute greatly toward better understanding the nature of soils.

4.1 Statistical Method

The data presented in this report generally involved two variables. The data were collected and arranged in such a manner that it was possible to describe the data mathematically. Data showing corresponding values of variables were collected; then the corresponding variables were plotted as points on a rectangular coordinate system. With only two variables involved, there was the potential for simple correlation and simple regression.

The method of least squares* is a powerful method for obtaining the most reliable possible information from a set of experimental observations. Curve fitting by this method simply involves choosing a curve for which the sum of the squares of the deviations of data from the curve is minimum. A curve satisfying this criterion is said to be the best-fit curve or is said to fit the data in the least square sense. The resulting curve is called the regression curve. The best-fit curves

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* References 13-16 are cited as sources of complete definitions and thorough explanations of the statistical procedures used in this study. Statistical terms and procedures are briefly defined in Appendix A.

or lines and regression equations presented in the following paragraphs were developed by use of a computer. Standard deviations in the Y-axis are presented. Generally, the lines of regression were described by the equation:

$$Y = a_o + a_1X \tag{2}$$

however, in some instances, the second degree polynomial,

$$Y = a_o + a_1X + a_2X^2 \tag{3}$$

was found to fit the data better. The second degree polynomial gives a parabola whose axis is vertical; however, only small segments of such a parabola appear in the process of fitting the data. The data were correlated by either linear or nonlinear regression lines based on the lowest computed standard error of estimate between each. The least square lines or curves presented herein are regression lines or curves of Y on X. The standard error of estimate is therefore a measure of deviation from the regression line or curve in the Y axis. The standard error of estimate has the same properties as the standard deviation of a frequency histogram in that, if lines were constructed parallel to the regression line or curve of Y on X at a vertical distance of the standard error of estimate, they would contain 68 percent of the data points.[17] Correlation of relationship between soil properties are represented by regression lines or curves. In some instances, the scatter diagram, which shows the location of points (X, Y) on the rectangular coordinate system, showed no correlation. In some cases, the mathematical nonlinear curves of regression were modified near the outer limits of the curves to provide smooth positive or negative correlation curves

that best fit the data. Therefore, the equations are only applicable to approximately the two-thirds of these correlation curves that is nearest the axis.

4.2 Plasticity Index and Liquid Limit

One of the best known methods of classifying soils on the basis of plasticity is the use of the plasticity chart (fig. 4-1). It has been observed that many properties of clays and silts can be correlated with the Atterberg limits by means of the plasticity chart.[8] It has been found that the data for soils of a given geologic origin tend to fall on a line more or less parallel to the A-line. The U-line is the expected upper limit below which most soils plot on the plasticity chart. As the liquid limit of soils represented by such a line increases, the plasticity and compressibility of the soil also increase. Inorganic clays plot above the A-line and organic clays and silts plot below. Organic soils are also distinguished by their characteristic odor and dark color.

A summary of the correlations between liquid limit and plasticity index is shown in table 4-1. An equation is presented for each correlation. Standard deviations are given for each line of regression. The plasticity charts for each deposit studied are shown in figs. 4-2a through 4-4b.

The regression equation for the prodelta deposits compares favorably with the regression equation of $PI = 0.831LL - 14.0$ which was developed by McClelland.[19] McClelland's work was based on 53 samples of prodelta clays from the continental shelf in the Gulf of Mexico. The standard

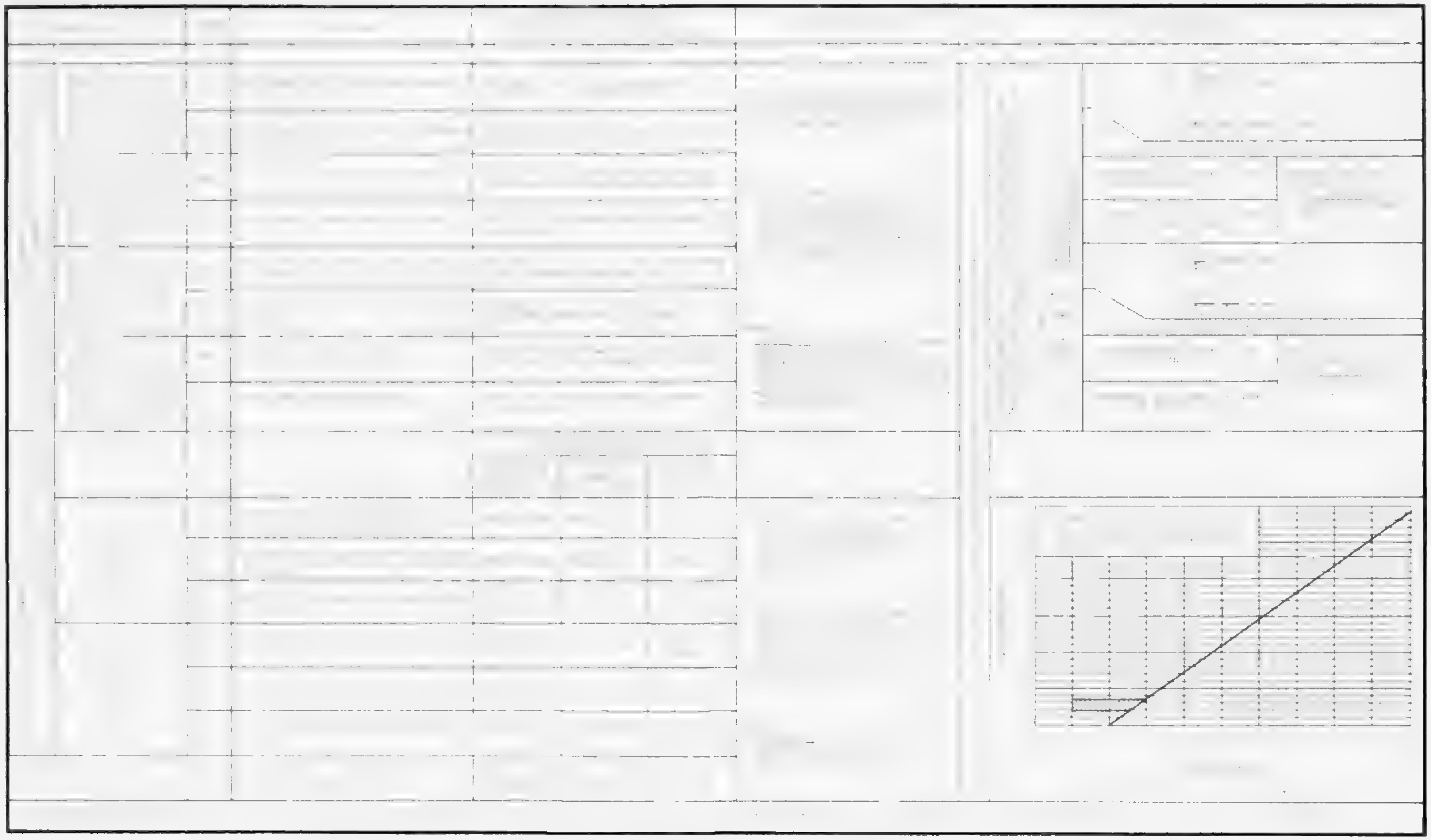


Fig. 4-1. Unified Soil Classification System[20]

deviation for the equation developed by McClelland was not reported.

Sherman and Hadjidakis[18] reported an equation of PI 0.795LL - 8.09 with a standard deviation of 5.71. Their work was based on 125 tests on backswamp deposits at the Morganza Floodway Control Structure. This equation compares reasonably close to the equation reported in table 4-1. Thus indicating that similar soils (although the backswamp deposits at Morganza Floodway are alluvial valley deposits) fall on a line approximately parallel to the A-line and can be represented by a line of regression equation.

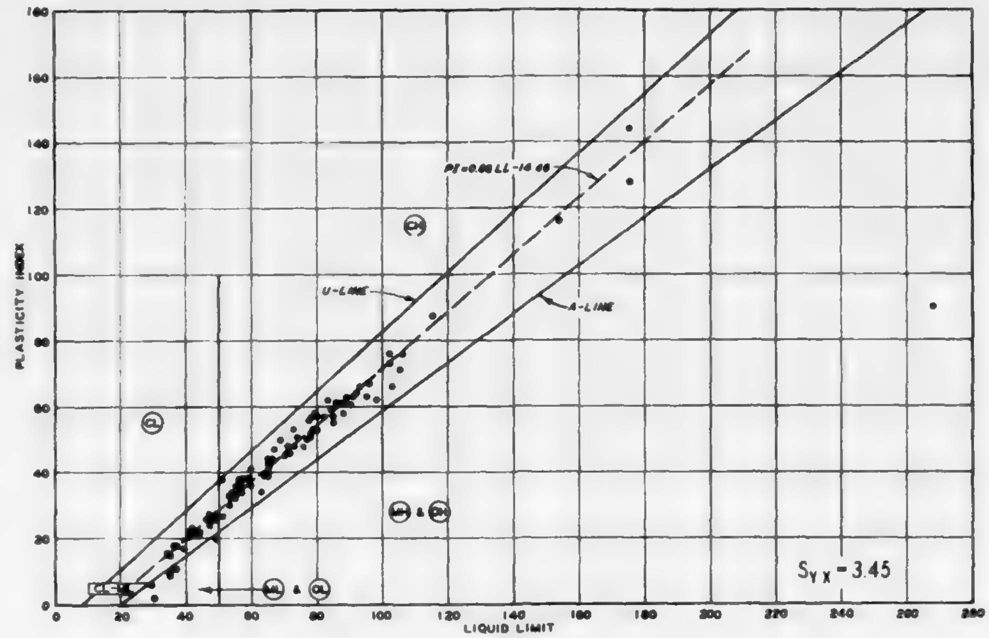
TABLE 4-1

SUMMARY OF CORRELATION BETWEEN LIQUID LIMIT AND PLASTICITY INDEX

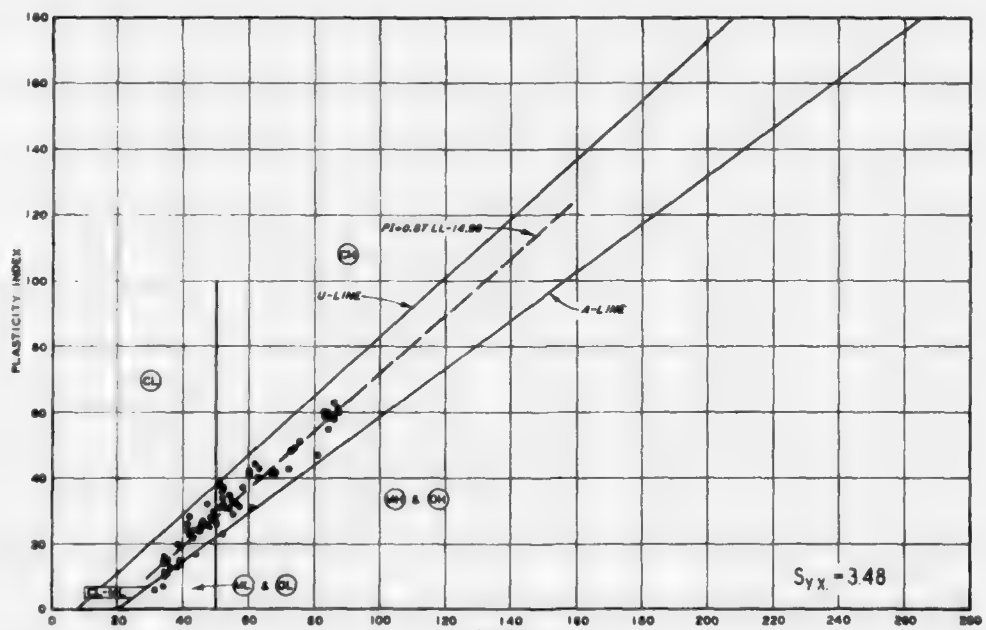
DEPOSIT	FIGURE	LINE OF REGRESSION	STANDARD DEVIATION
Natural Levee	4-2a	PI = 0.86LL - 14.46	3.45
Point Bar	4-2b	PI = 0.87LL - 14.99	3.48
Interdistributary	4-3a	PI = 0.79LL - 9.27	4.69
Intradelta	4-3b	PI = 0.81LL - 11.3	3.80
Prodelta	4-4a	PI = 0.79LL - 8.48	5.70
Backswamp	4-4b	PI = 0.73LL - 6.81	6.32

4.3 Specific Gravity and Plasticity Index

All calculations involving the fundamental properties of a soil mass require the use of the specific gravity (G_s) of the solids. The specific gravity must be known with reasonable accuracy for the reduction of data from laboratory shear and consolidation tests. Ranges and

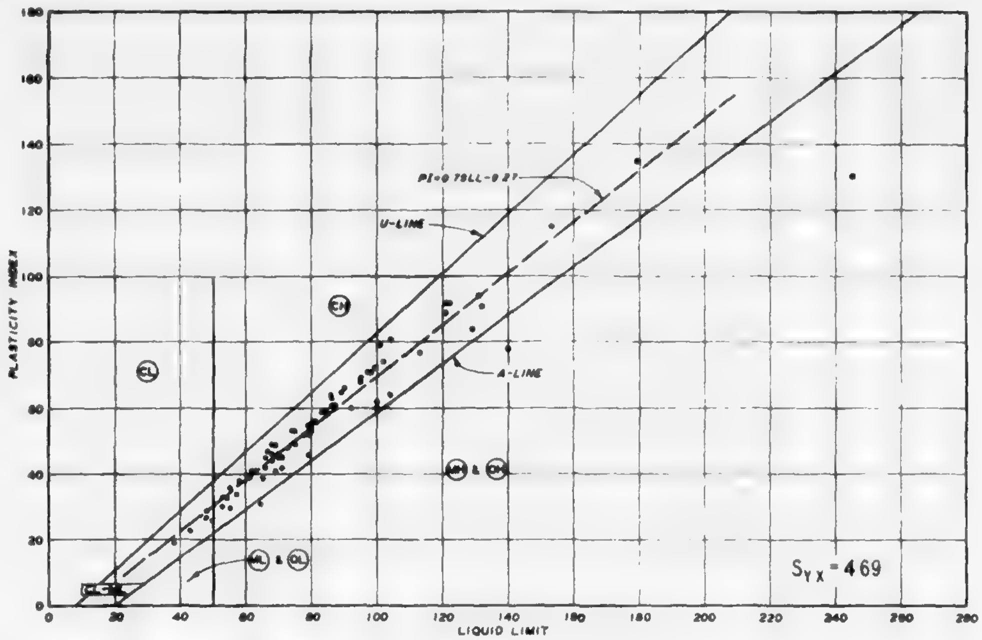


a. Natural levee

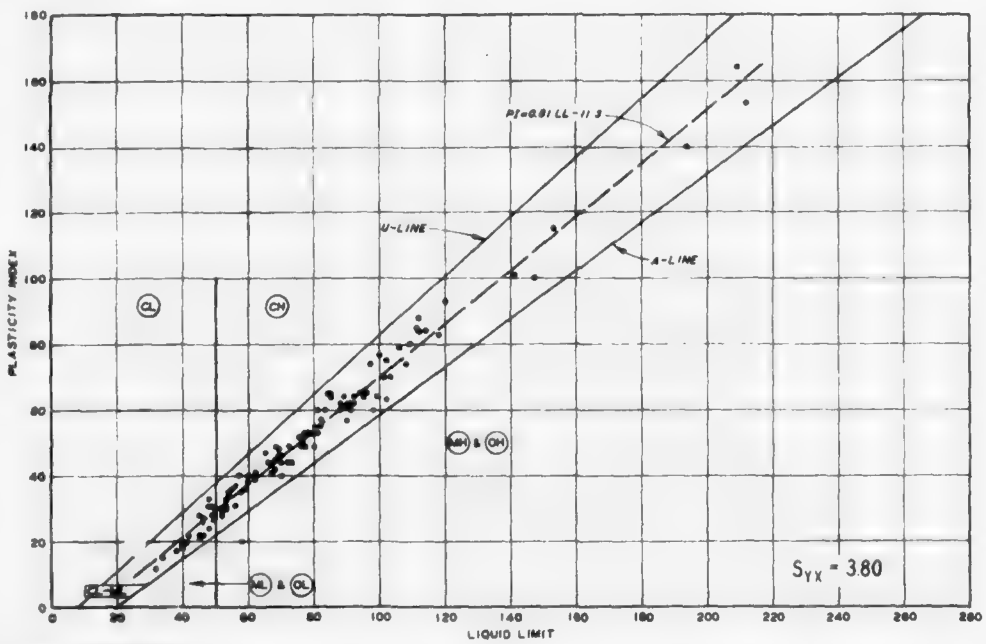


b. Point bar

Fig. 4-2. Plasticity charts for natural levee and point bar deposits

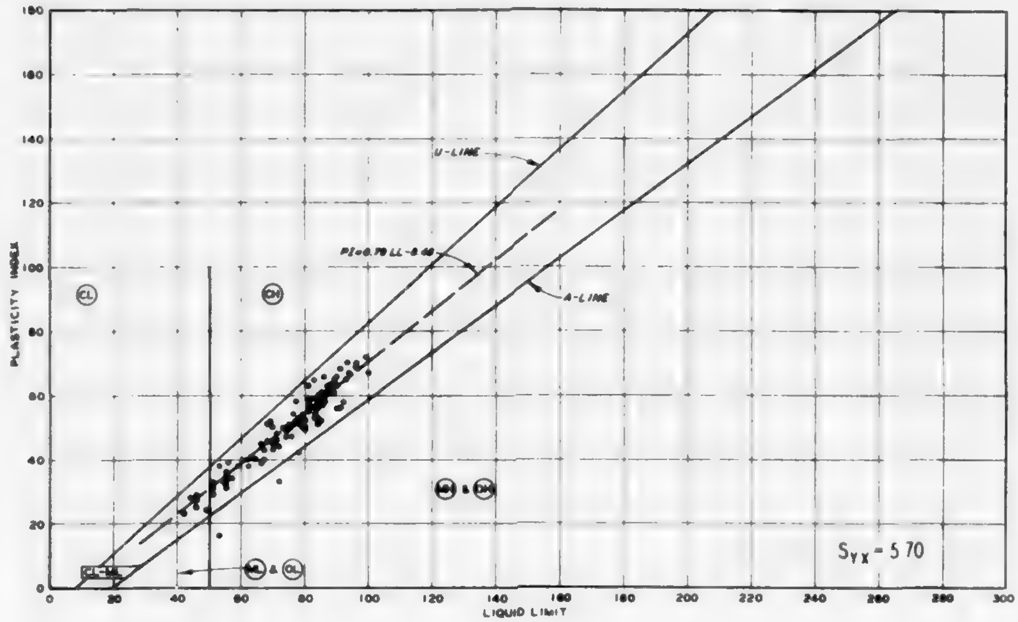


a. Interdistributary

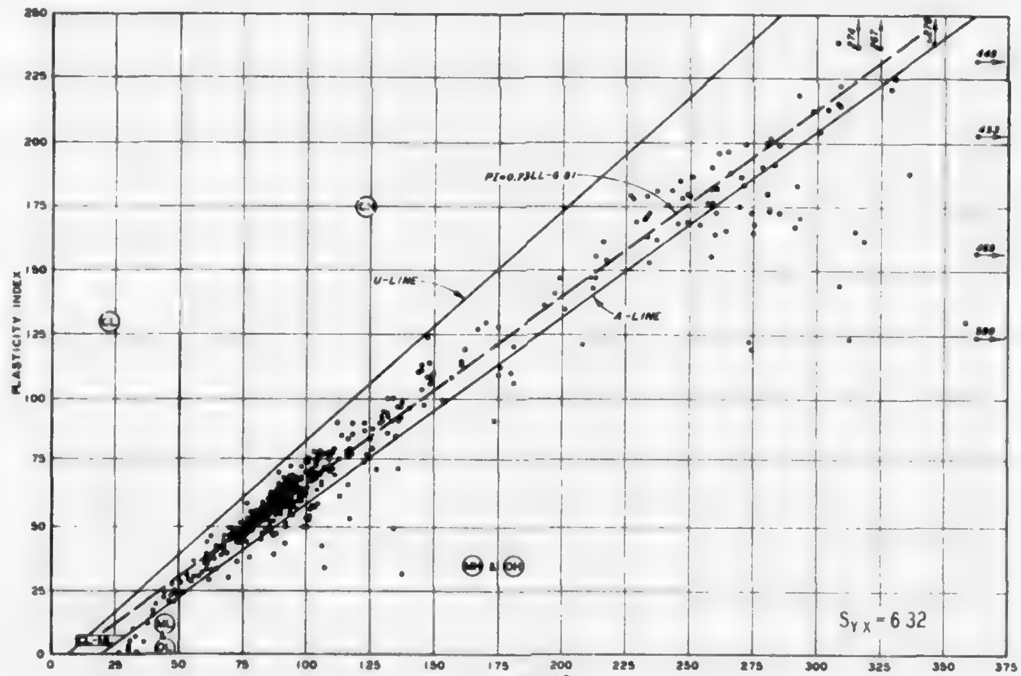


b. Intradelta

Fig. 4-3. Plasticity charts for interdistributary and intradelta deposits



a. Prodelta



b. Backswamp

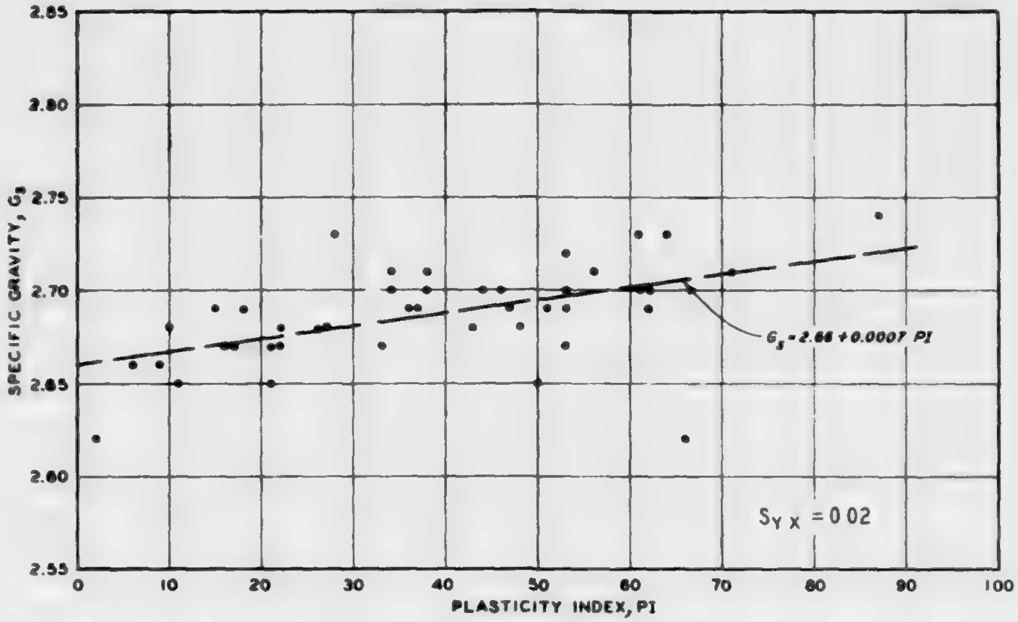
Fig. 4-4. Plasticity charts for prodelta and backswamp deposits

averages of specific gravity were presented in Chapter II of this study. For this discussion, specific gravity was correlated with plasticity index. A summary of the correlations is provided in table 4-2. In figs. 4-5 through 4-8, it is shown that the specific gravities for inorganic deltaic deposits have a positive correlation with plasticity index; while a negative correlation is shown for organic deltaic deposits. Reasonably good correlations exist for all the deposits, with the greatest scatter reflected in data for the organic backswamp deposits. The correlations shown in figs. 4-5 through 4-8, supplemented by the specific gravity frequency histograms shown in figs. 2-12 and 2-13, provide some basis for estimating specific gravities for the deltaic deposits.

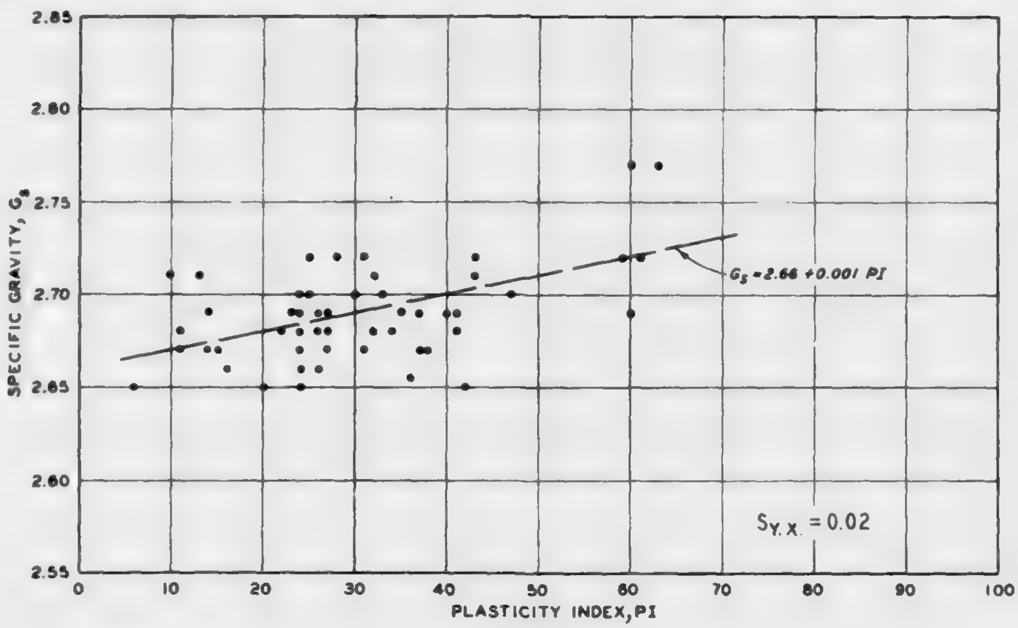
TABLE 4-2

SUMMARY OF CORRELATIONS BETWEEN SPECIFIC GRAVITY AND PLASTICITY INDEX

DEPOSIT	FIGURE	LINE OF REGRESSION	STANDARD DEVIATION
Natural Levee	4-5a	$G_s = 2.66 + 0.0007PI$	0.02
Point Bar	4-5b	$G_s = 2.66 + 0.001PI$	0.02
Interdistributary	4-6a	$G_s = 2.66 + 0.001PI$	0.02
Intradelta	4-6b	$G_s = 2.68 + 0.0003PI$	0.04
Prodelta	4-7	$G_s = 2.68 + 0.001PI$	0.02
Backswamp (Inorganic)	4-8a	$G_s = 2.65 + 0.0004PI$	0.04
Backswamp (Organic)	4-8b	$G_s = 2.81 - 0.003PI$	0.11

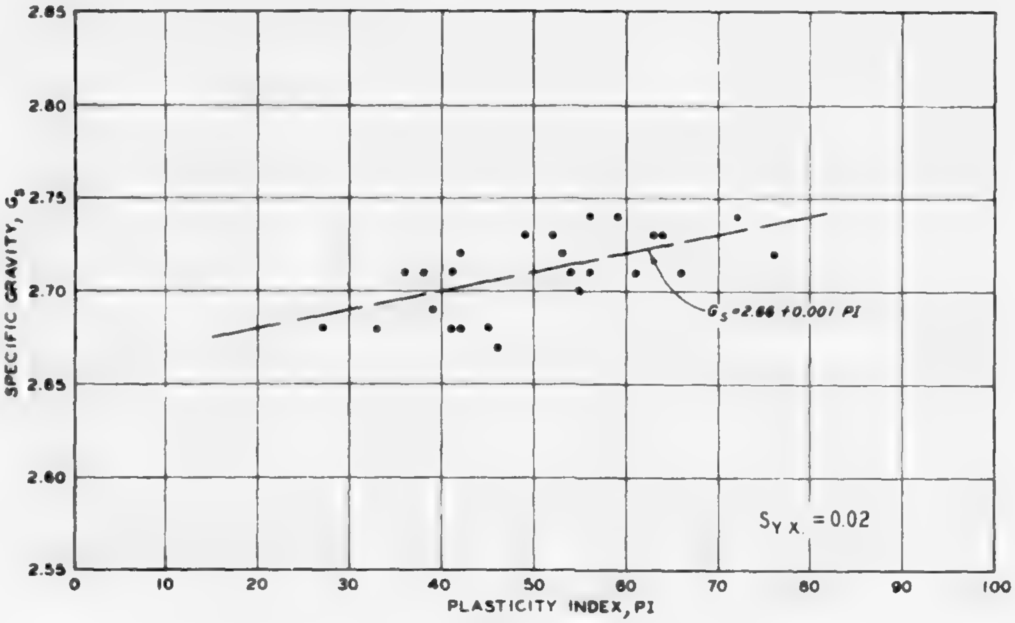


a. Natural levee

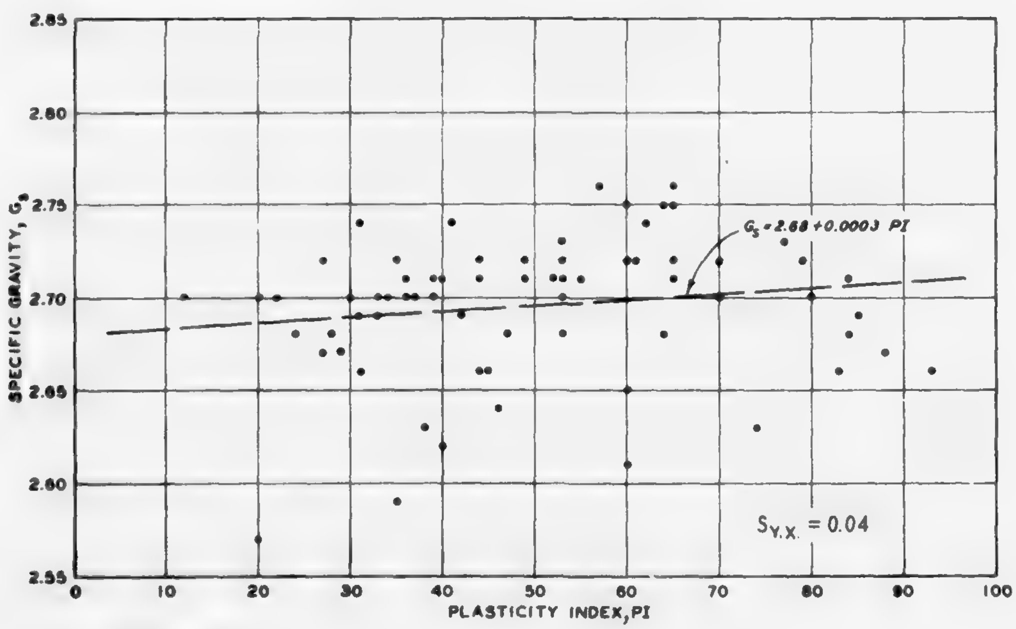


b. Point bar

Fig. 4-5. Correlation between G_s and PI for natural levee and point bar deposits



a. Interdistributary



b. Intradelta

Fig. 4-6. Correlation between G_s and PI for interdistributary and intradelta deposits

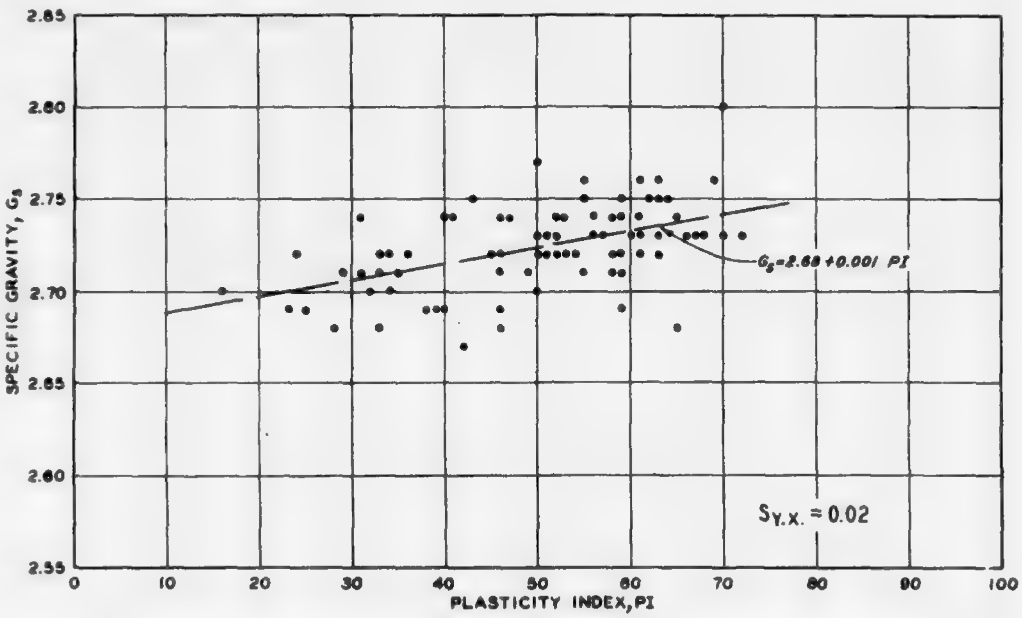
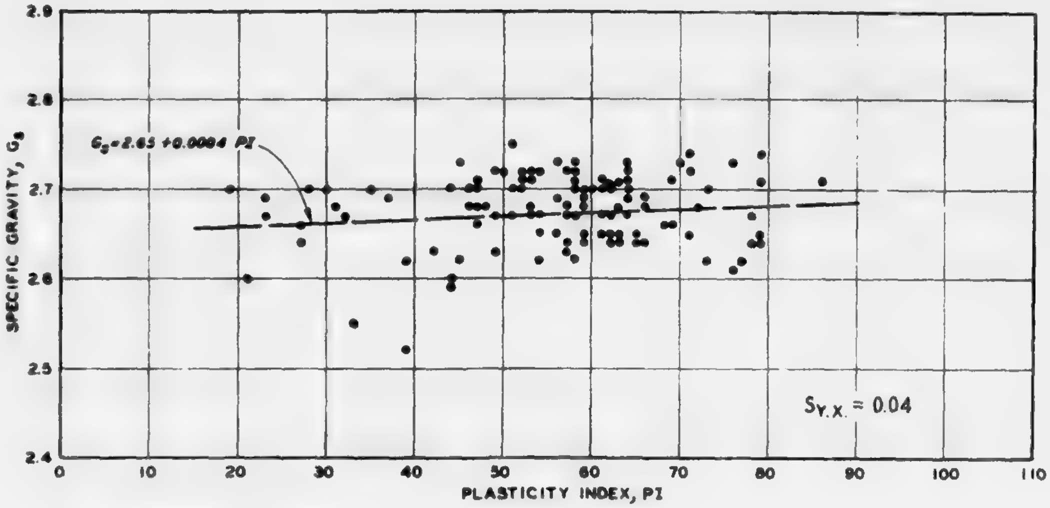
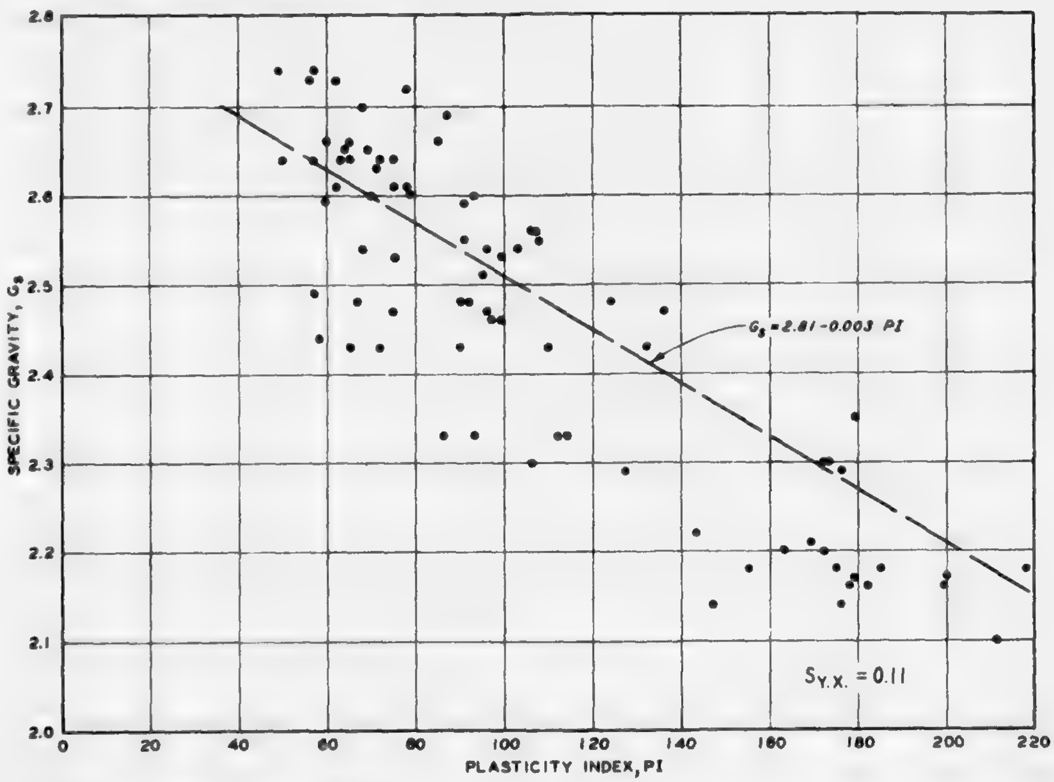


Fig. 4-7. Correlation between G_s and PI for prodelta deposits



a. Backswamp (inorganic)



b. Backswamp (organic)

Fig. 4-8. Correlation between G_s and PI for inorganic and organic backswamp deposits

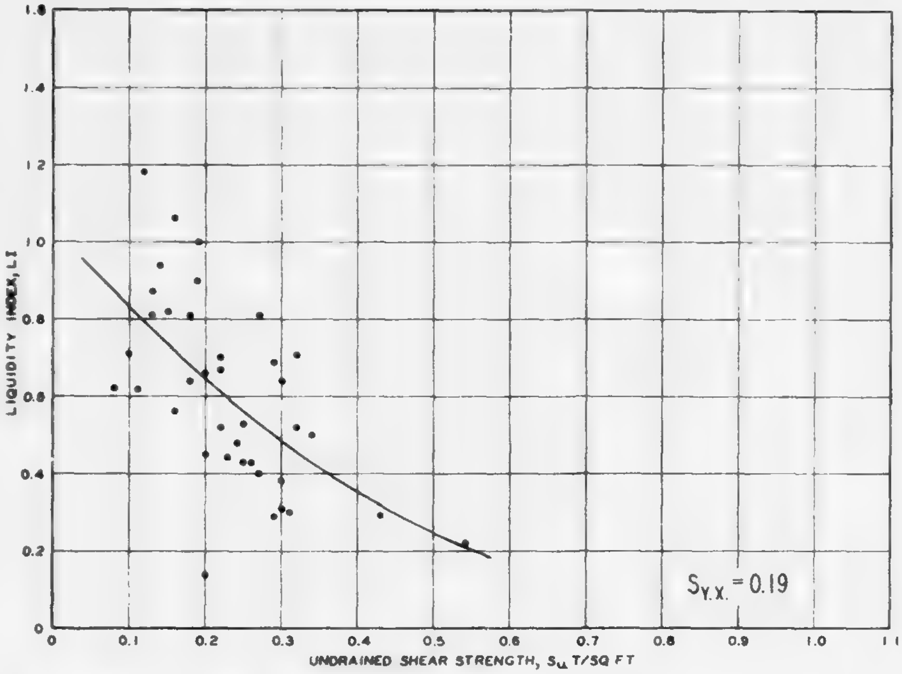
4.4 Shear Strength Characteristics

4.4.1 Undrained Shear Strength and Liquidity Index

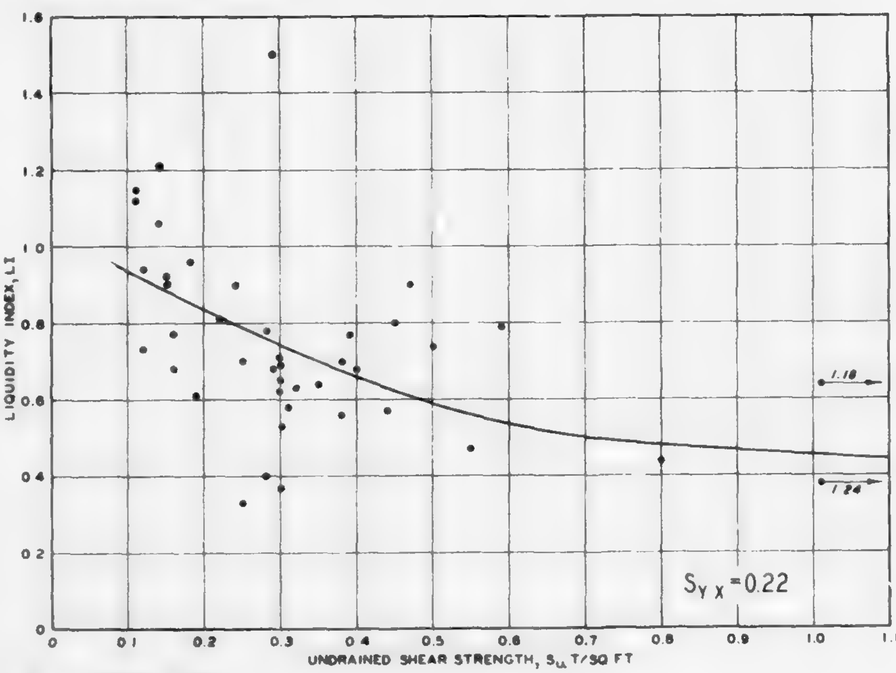
Relationships between liquidity index (LI) and unconfined compressive strength for Chicago clays are given in reference 21. This suggested that similar correlations could be made for other soils that have the same geological origin. A well-defined relationship between undrained shear strengths and the index properties of soils is needed. Means for accurately estimating s_u would be helpful to design engineers as a supplement to laboratory shear strength data. The plots of liquidity index versus s_u in figs. 4-9 through 4-11 permit estimates of s_u for the deltaic deposits based on relatively inexpensive laboratory tests. Based on the least squares method, the resulting best-fit line is nonlinear. This nonlinear correlation of data is represented satisfactorily by the second degree polynomial. The best-fit curves resulted in negative nonlinear correlations for all the deltaic deposits investigated.

4.4.2 s_u/p_o Ratio and Plasticity Index

In reference 8 Skempton is quoted as suggesting that a constant ratio should exist between the undrained shear strength and the effective overburden pressure for normally consolidated soils of similar geologic origin that have a constant plasticity index. It has also been found that a correlation exists between s_u/p_o ratio and plasticity index for reasonably homogeneous normally consolidated deposits.[8] This correlation has been found to exist over a wide range of types of sedimented clays. Such a correlation makes it possible to roughly estimate

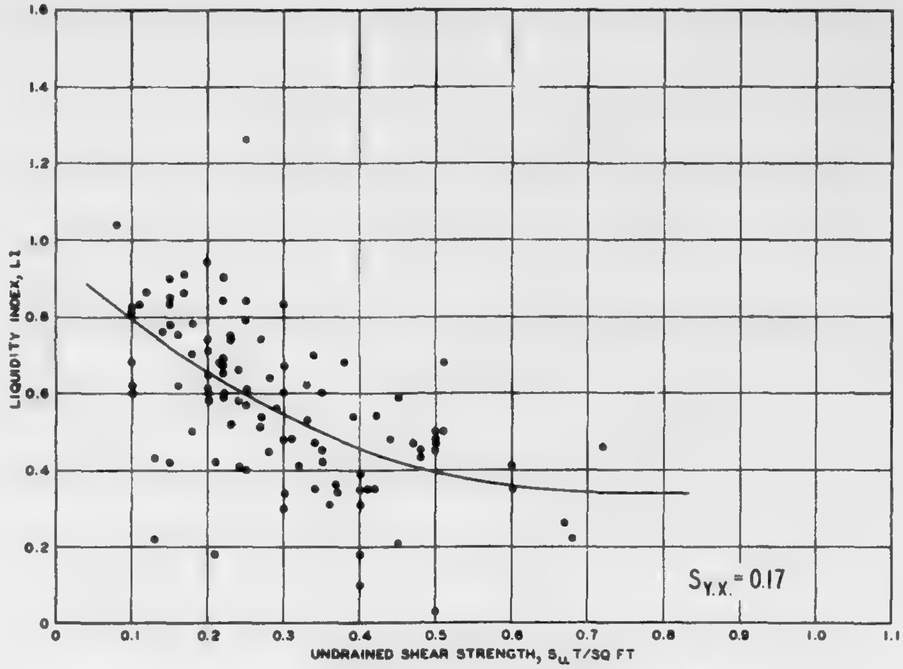


a. Natural levee

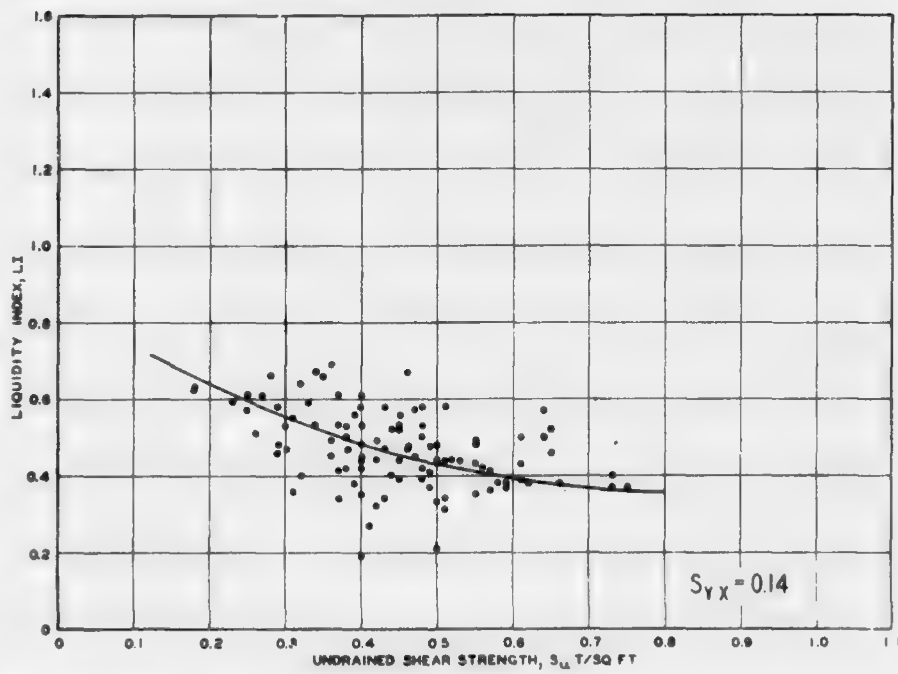


b. Point bar

Fig. 4-9. Correlation between s_u and LI for natural levee and point bar deposits



a. Backswamp (inorganic)



b. Prodelta

Fig. 4-10. Correlation between s_u and LI for inorganic backswamp and prodelta deposits

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CORRELATION OF ENGINEERING PROPERTIES OF COHESIVE SOILS BORDERI--ETC(U)
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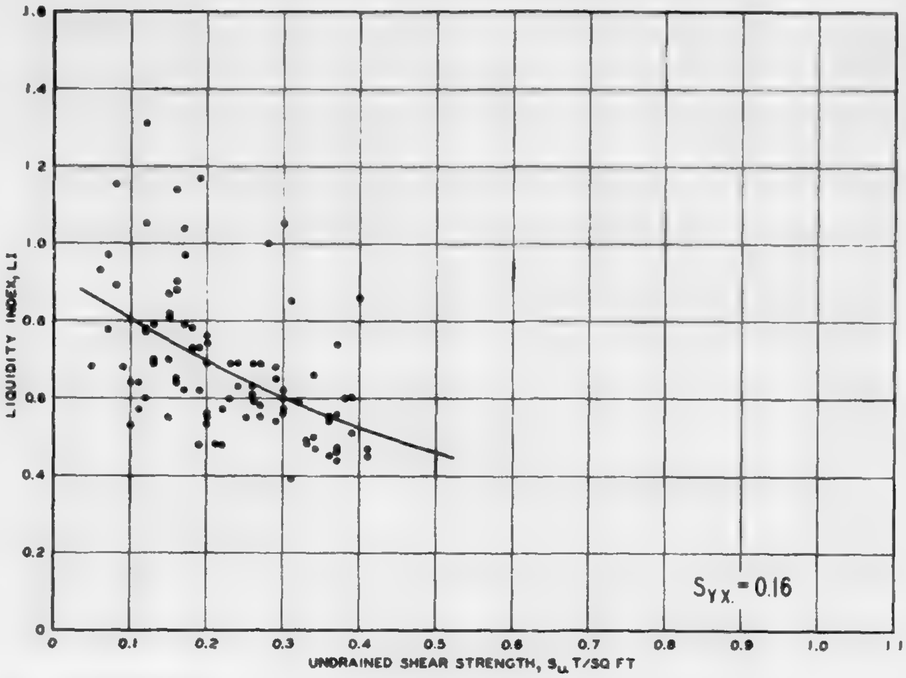
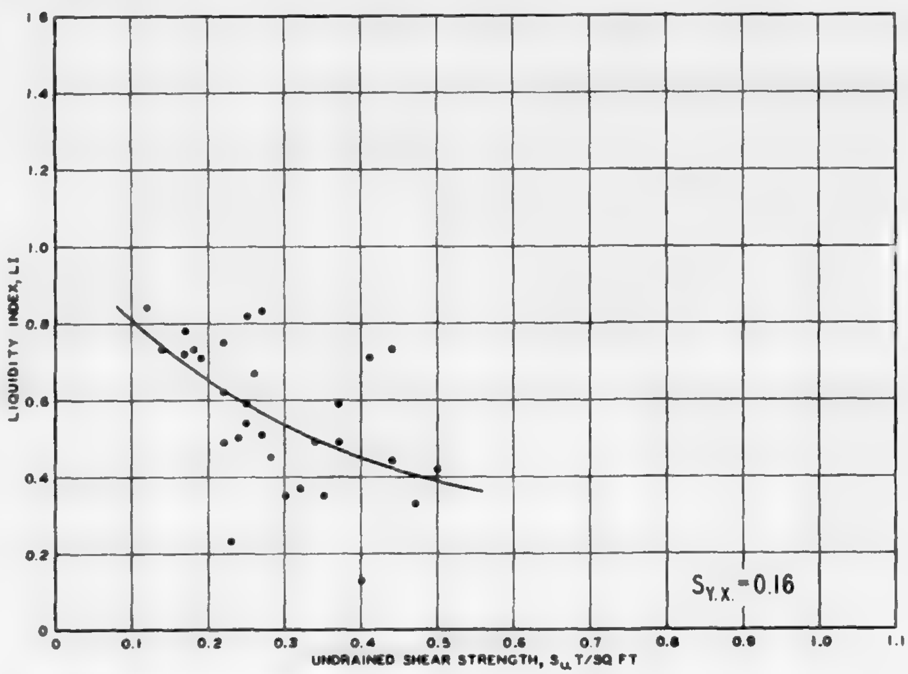


a. Intradelta



b. Interdistributary

Fig. 4-11. Correlation between s_u and LI for intradelta and interdistributary deposits

the undrained shear strength of normally consolidated deposits on the basis of results from Atterberg limit tests; however, if undrained shear strengths are available from laboratory tests, it may be possible to determine whether the deposit is normally consolidated or overconsolidated by comparing the laboratory data with the correlations shown in fig. 4-12. Undrained shear strengths from normally consolidated soils should agree reasonably well with the correlation trends, overconsolidated soils would not correlate. Plots of s_u/p_o ratio versus plasticity index are shown in fig. 4-12. In contrast to the positive correlation suggested in reference 8, the data for the deltaic deposits indicate both positive and negative, and no correlation. There is no apparent explanation for these relations. The natural levee deposits were not investigated because of their overconsolidated nature.

4.4.3 Drained Shear Strength and Plasticity Index

The shear strength parameters from drained shear strength tests (S-tests) are designated as the angle of internal friction ϕ' and cohesion c'. These shear strength parameters used in this report were obtained by a straight line approximation of the data. The drained shear strength for normally consolidated cohesive soils can be expressed with satisfactory accuracy by Coulomb's equation in which $c' = 0$.[8] Thus

$$s_d = p_o \tan \phi' \tag{4}$$

where

s_d = shear strength

p_o = effective overburden pressure

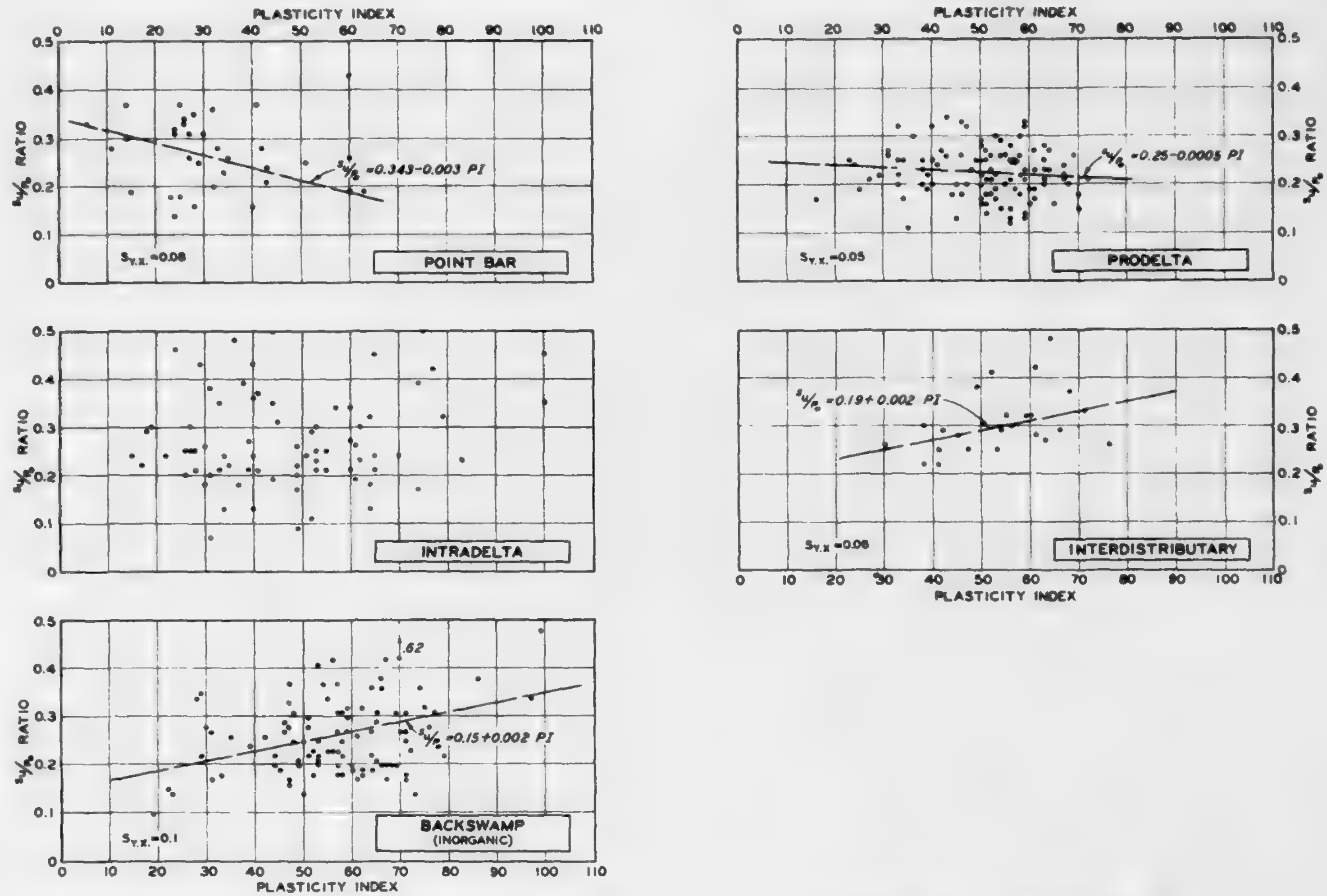


Fig. 4-12. s_u/p_o ratio versus plasticity index for point bar, intradelta, inorganic backswamp, prodelta, and interdistributary deposits

It is, therefore, considered reasonable to omit the c' parameter when defining the drained shear strength, although the c' values ranged between 0 and 0.30 ton per sq ft. Bjerrum and Simmons,[22] Sherman and Hadjidakis,[18] and others have reported correlations between ϕ' and plasticity index for normally consolidated clays. The values of ϕ' seem to decrease as plasticity increases. Correlations of ϕ' with plasticity index are shown in figs. 4-13 and 4-14. Insufficient data were available for individual types of deltaic deposits located along the river, so they were correlated as a group and called "deltaic". The data representing this group is from tests on reasonably normally consolidated soils. Correlations of ϕ' and PI for the inorganic backswamp deposits are shown in fig. 4-14. The correlation of data for the inorganic backswamp deposits shown in fig. 4-14a is based on data from normally consolidated soils. The correlation of data shown in fig. 4-14b should be used with caution because the inorganic backswamp soils represented by this plot are slightly overconsolidated. The c' parameter was not correlated with PI. No correlations existed between ϕ' and PI for the organic backswamp deposits. The standard deviations from the regression lines varied from 1.75 to 3.84 units of friction angle.

4.5 Consolidation Characteristics

4.5.1 Compression Index and Index Properties

Relationships between compression index and index properties such as natural water content and liquid limit have been established in public literature. Terzaghi and Peck[8] reported a correlation between compression index and liquid limit for normally consolidated soils and suggested

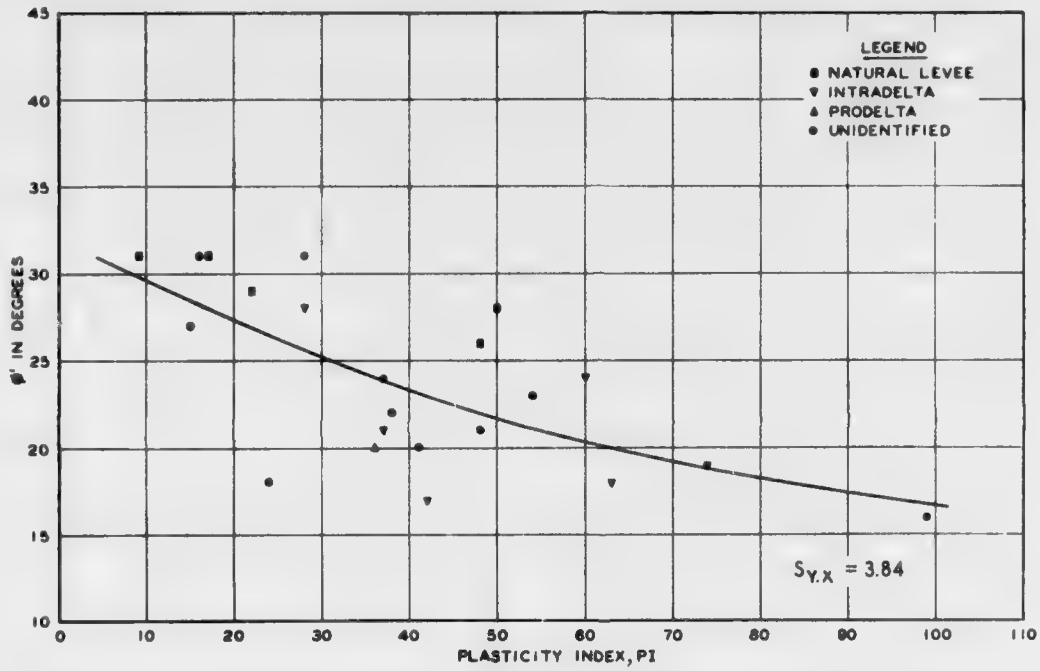
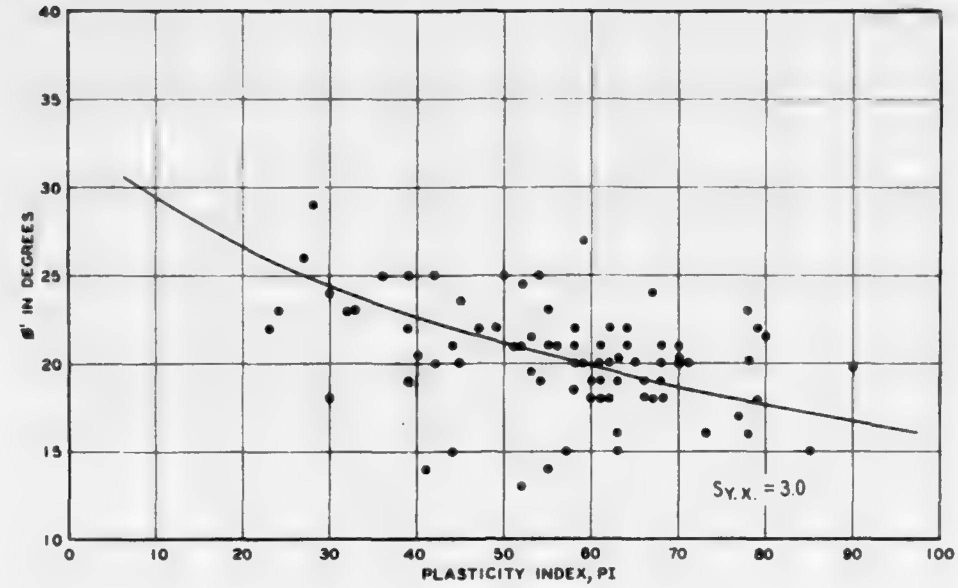
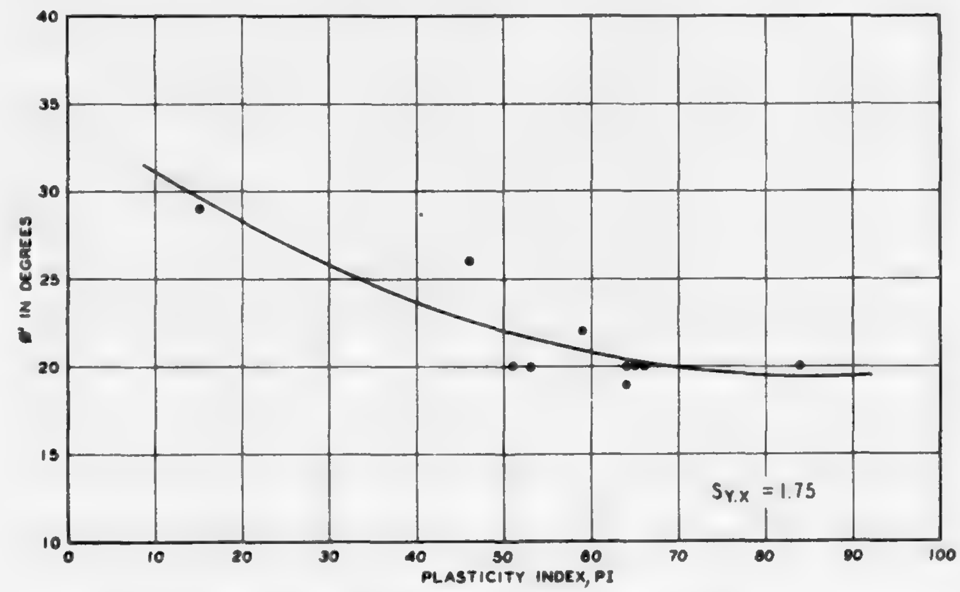


Fig. 4-13. Correlation of drained shear strength with plasticity index for deltaic deposits



a. Normally consolidated inorganic backswamp deposits



b. Overconsolidated inorganic backswamp deposits

Fig. 4-14. Correlation of drained shear strength with plasticity index for inorganic backswamp deposits

that the line of regression can be represented by the equation:

$$C_c = 0.009LL - 0.09 \tag{5}$$

Sherman and Hadjidakis[18] reported similar correlations for the Mississippi Valley alluvial soils, as well as correlations between natural water content and compression index for the alluvial valley soils. Appreciable differences were found between correlations of compression index and index properties of normally consolidated and overconsolidated soils. Sherman and Hadjidakis[18] suggested that the correlation between compression index and liquid limit can be represented by a linear line of regression with an equation of:

$$C_c = 0.011LL - 0.176 \tag{6}$$

The standard deviation from the regression line for their data was 0.137 unit of compression index. This correlation is in reasonably close agreement with that reported by Terzaghi and Peck. Correlations between compression index and natural water content and between compression index and liquid limit for deposits in the study area are discussed in the following paragraphs.

Correlations between compression index and soil index properties permit engineers to estimate the order of magnitude of settlement in a cohesive stratum caused by some applied external load without making any tests other than liquid limit and natural water content tests. These correlations have proven useful for estimating settlement in normally consolidated soils. The correlations of compression index with liquid limit appear to be more reliable than the correlation of compression index and natural water content. Based on the data presented herein, positive correlations exist between compression index and natural water

content and compression index and liquid limit for the deltaic deposits. The correlations can be represented by linear lines of regression. Summaries of correlations between water content and compression index, and liquid limit and compression index are shown in tables 4-3 and 4-4, respectively. The correlation plots are shown in figs. 4-15 through 4-21.

TABLE 4-3

SUMMARY OF CORRELATIONS BETWEEN WATER CONTENT AND COMPRESSION INDEX

DEPOSIT	FIGURE	LINE OF REGRESSION	STANDARD DEVIATION
Natural Levee	4-15a	$C_c = 0.017w - 0.46$	0.28
Point Bar	4-16a	$C_c = 0.011w - 0.12$	0.19
Interdistributary	4-17a	$C_c = 0.015w - 0.13$	0.19
Intradelta	4-18a	$C_c = 0.014w - 0.056$	0.20
Prodelta	4-19a	$C_c = 0.016w - 0.14$	0.13
Backswamp (Organic)	4-20a	$C_c = -0.91 + 0.027w - 0.000045w^2$	0.74
Backswamp (Inorganic)	4-21a	$C_c = 0.02w - 0.36$	0.33

TABLE 4-4

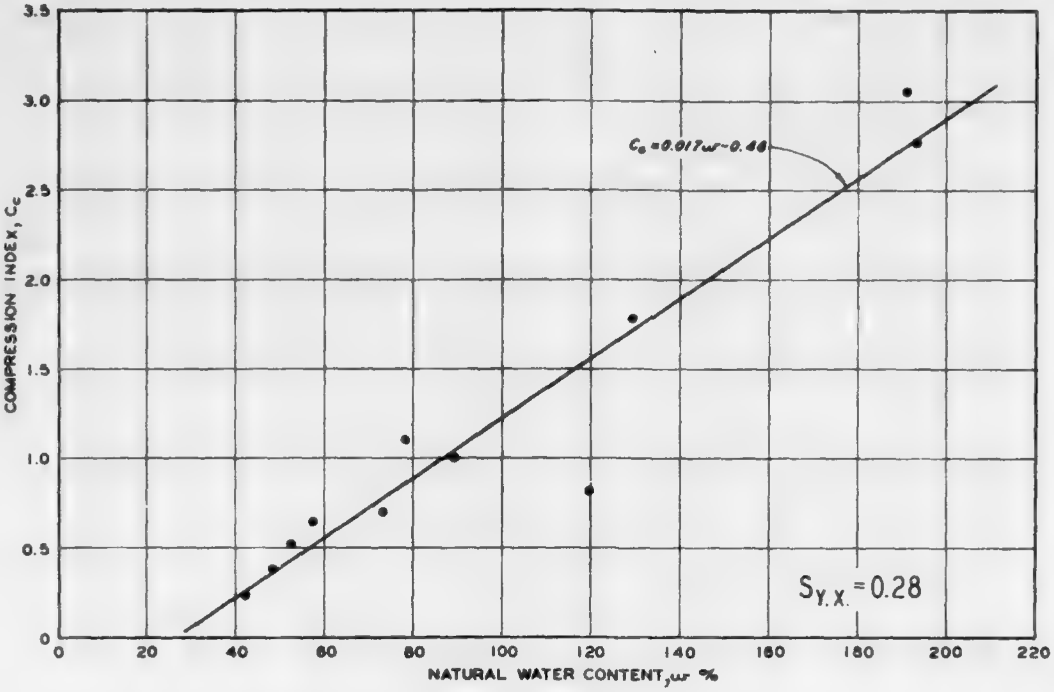
SUMMARY OF CORRELATIONS BETWEEN LIQUID LIMIT AND COMPRESSION INDEX

DEPOSIT	FIGURE	LINE OF REGRESSION	STANDARD DEVIATION
Natural Levee	4-15b	$C_c = 0.013LL - 0.37$	0.40
Point Bar	4-16b	$C_c = 0.011LL - 0.04$	0.24
Interdistributary	4-17b	$C_c = 0.014LL - 0.22$	0.21
Intradelta	4-18b	$C_c = 0.012LL - 0.12$	0.19
Prodelta	4-19b	$C_c = 0.01LL - 0.09$	0.12
Backswamp (Organic)	4-20b	$C_c = - 1.215 + 0.024LL - 0.000035LL^2$	0.75
Backswamp (Inorganic)	4-21b	$C_c = 0.013LL - 0.28$	0.36

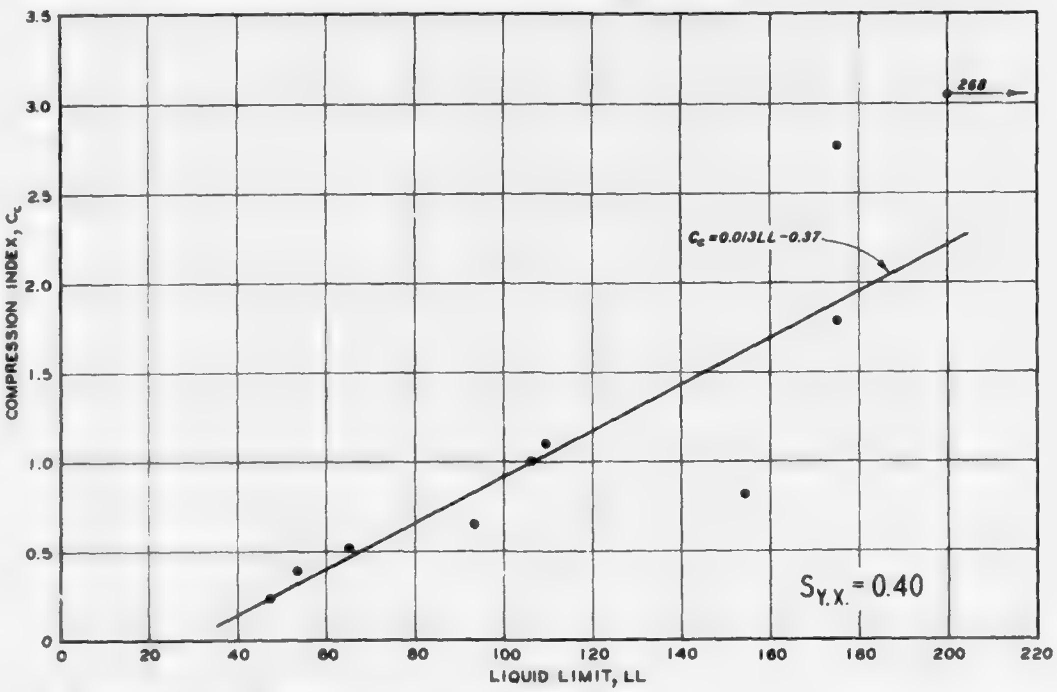
The equation shown in table 4-4 for prodelta deposits closely agrees with a correlation reported by McClelland[19] for prodelta clays from the continental shelf off southeastern Louisiana. McClelland's correlation is represented by equation:

$$C_c = 0.011LL - 0.176 \qquad (7)$$

Sherman and Hadjidakis[18] found the same correlation to exist between compression index and liquid limit for the Mississippi River alluvial deposits as noted from equation 6.

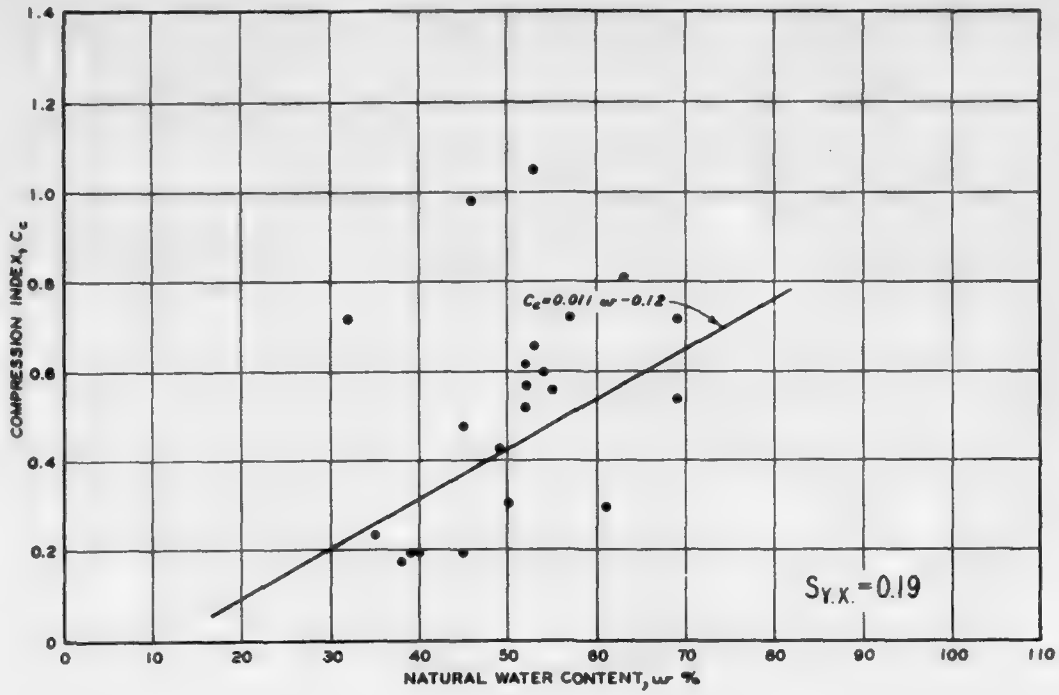


a. Compression index versus natural water content

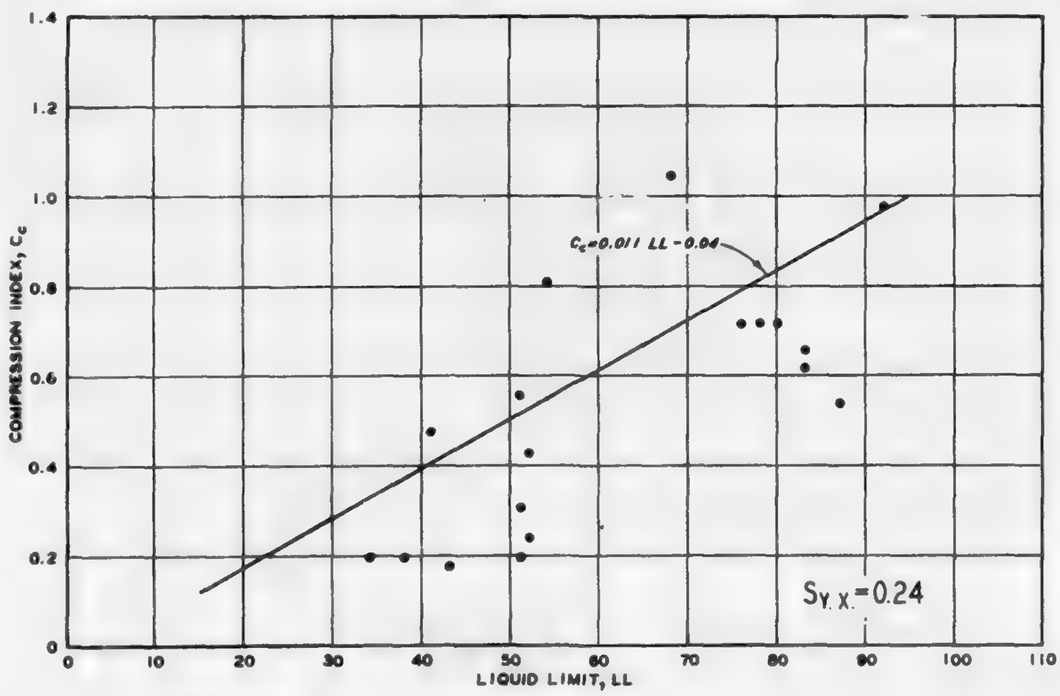


b. Compression index versus liquid limit

Fig. 4-15. Compression index correlations for natural levee deposits

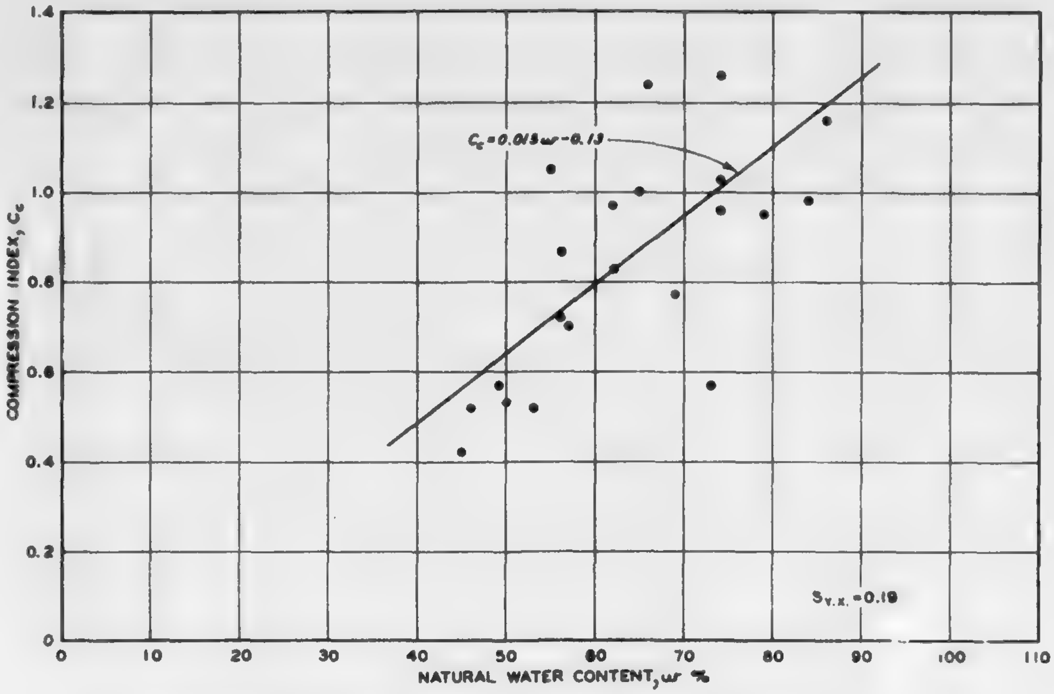


a. Compression index versus natural water content

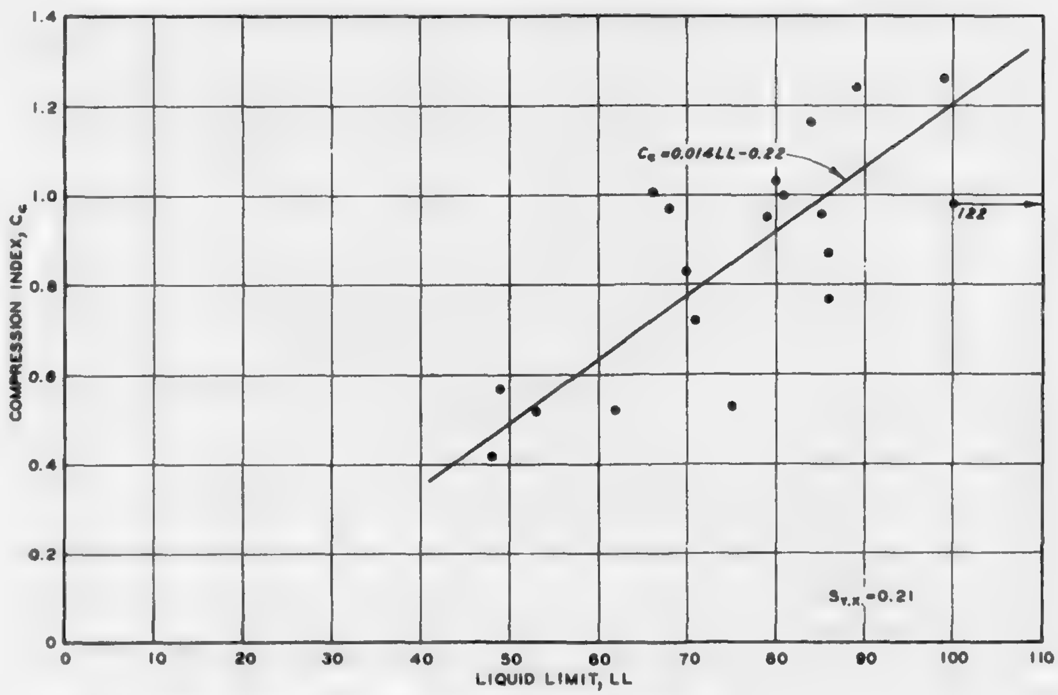


b. Compression index versus liquid limit

Fig. 4-16. Compression index correlations for point bar deposits

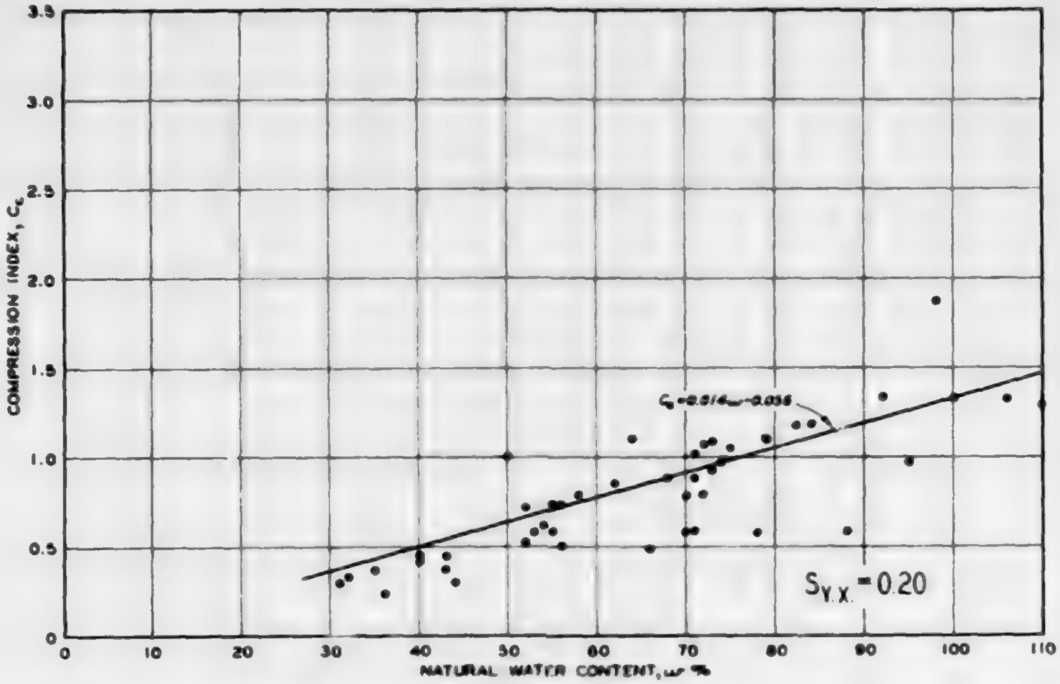


a. Compression index versus natural water content

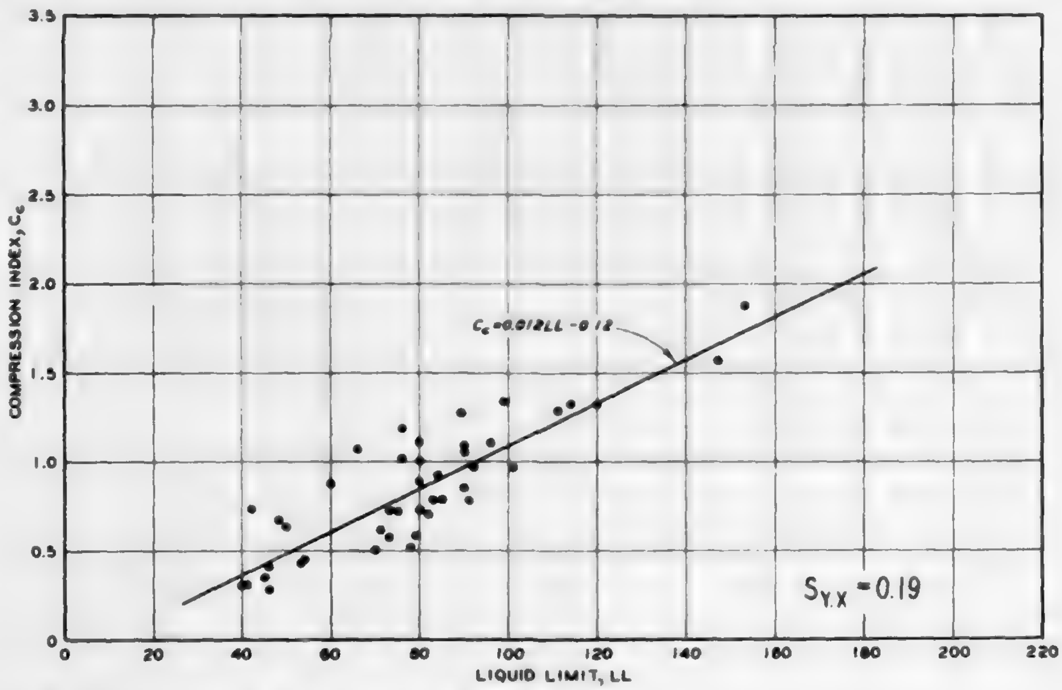


b. Compression index versus liquid limit

Fig. 4.17. Compression index correlations for interdistributary deposits

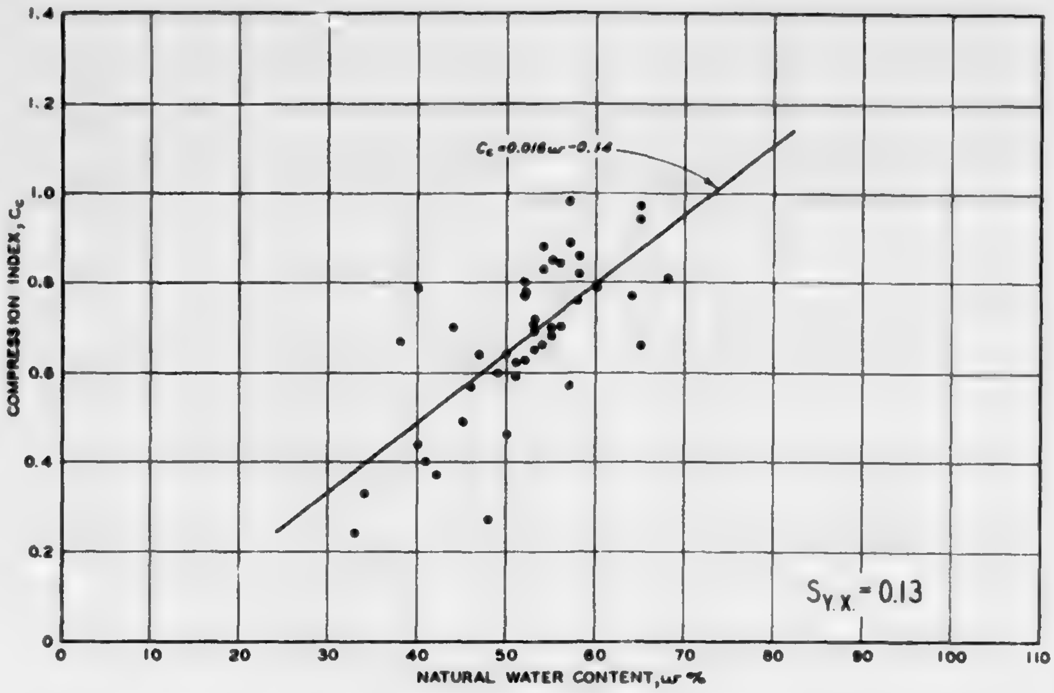


a. Compression index versus natural water content

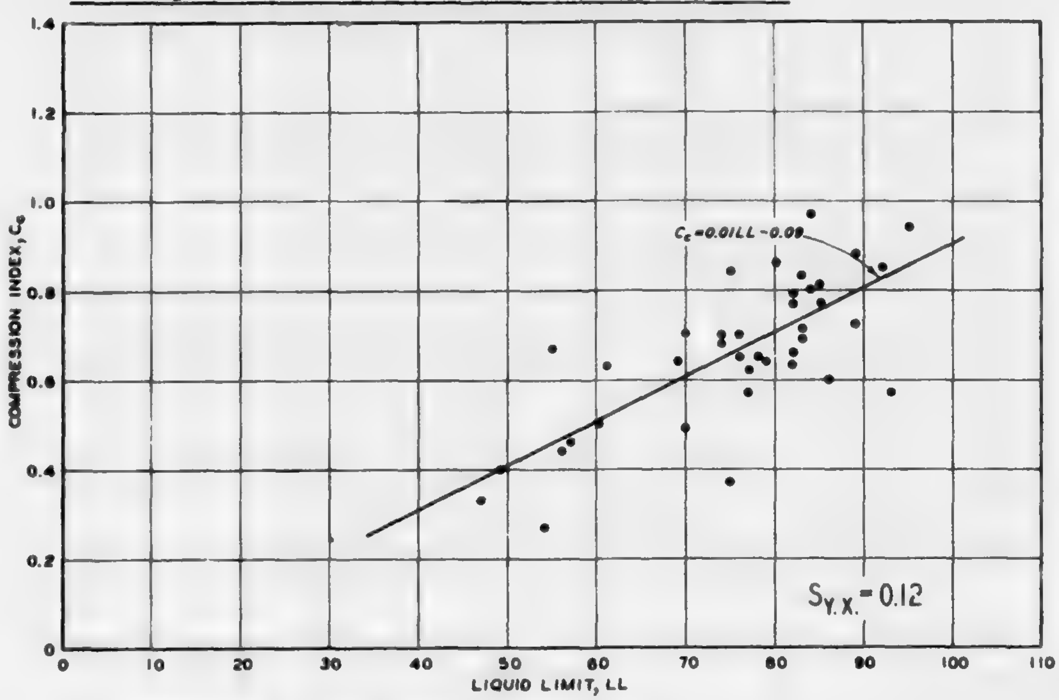


b. Compression index versus liquid limit

Fig. 4-18. Compression index correlations for intradelta deposits

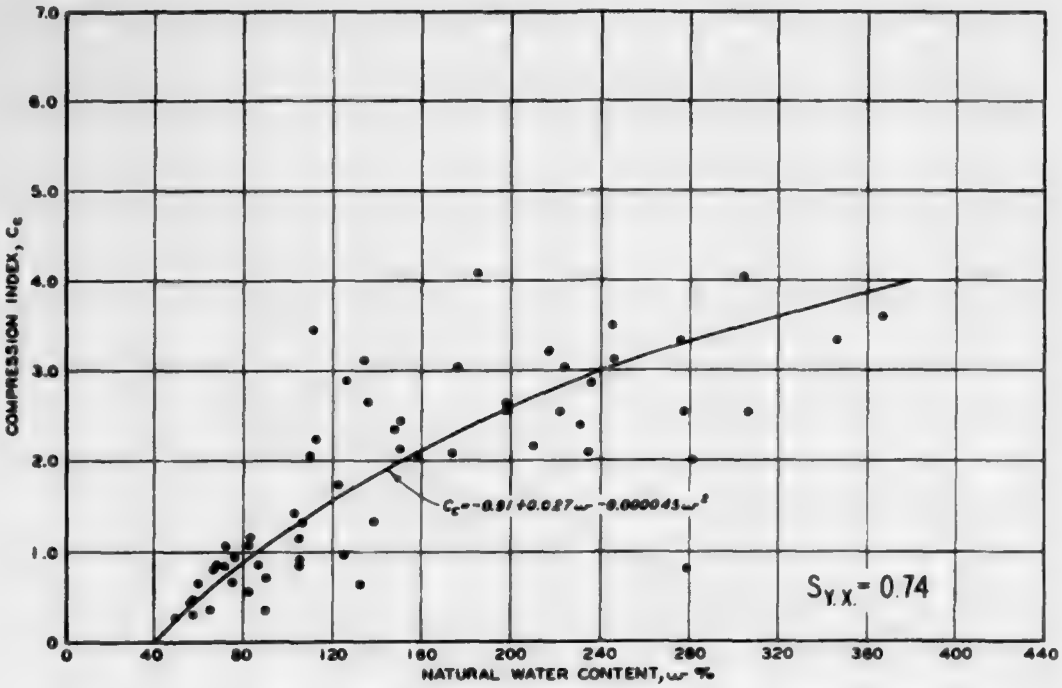


a. Compression index versus natural water content

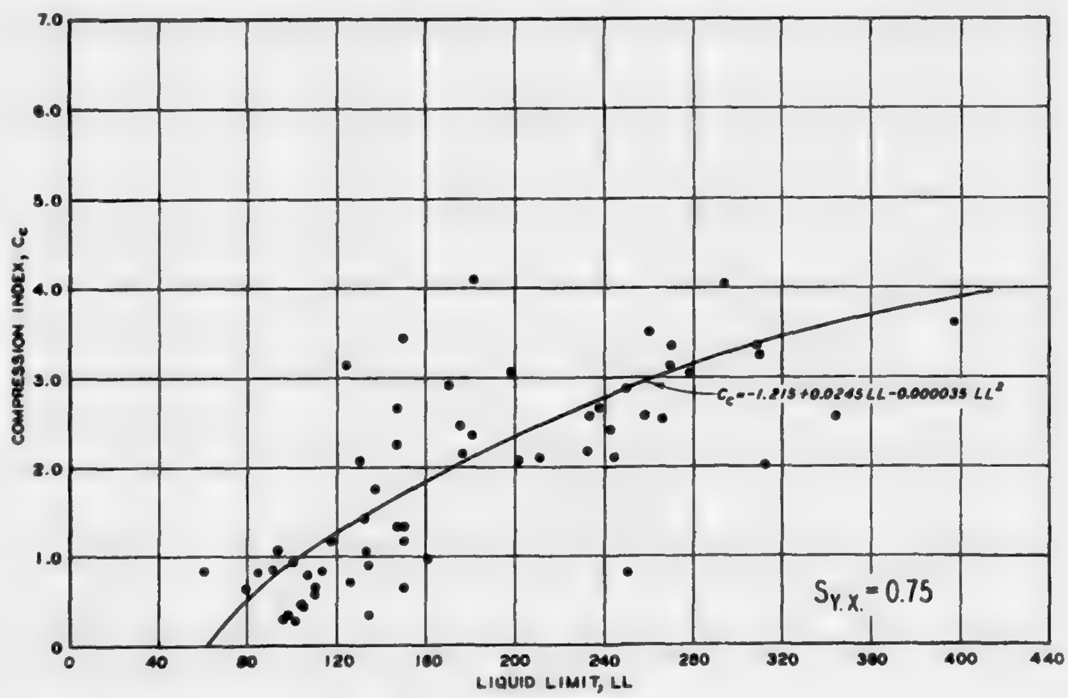


b. Compression index versus liquid limit

Fig. 4-19. Compression index correlations for prodelta deposits

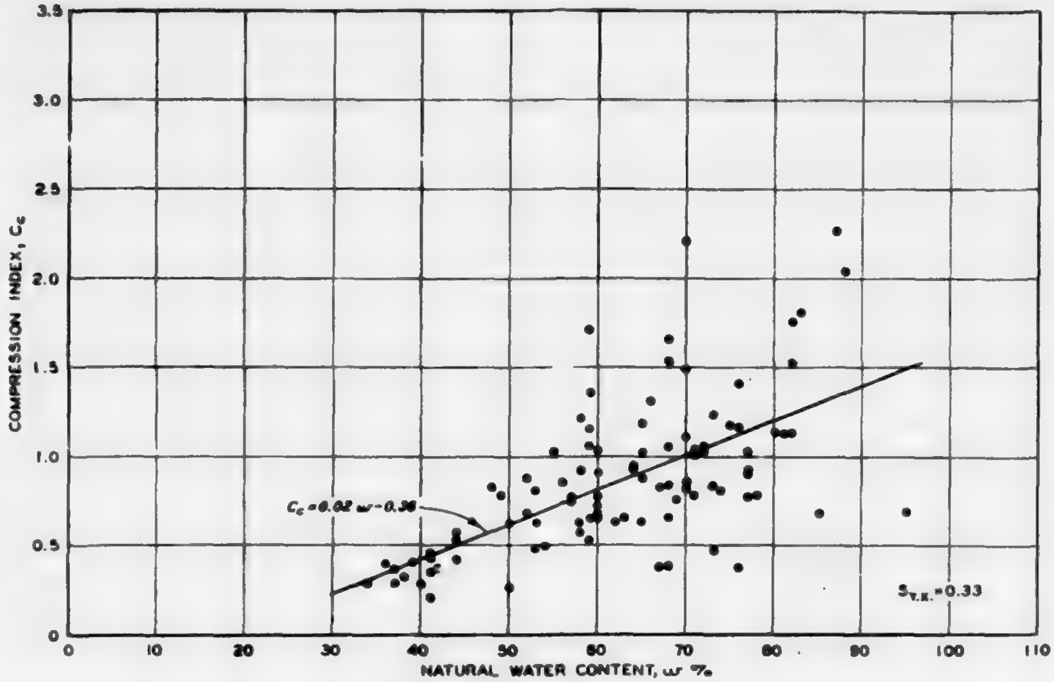


a. Compression index versus natural water content

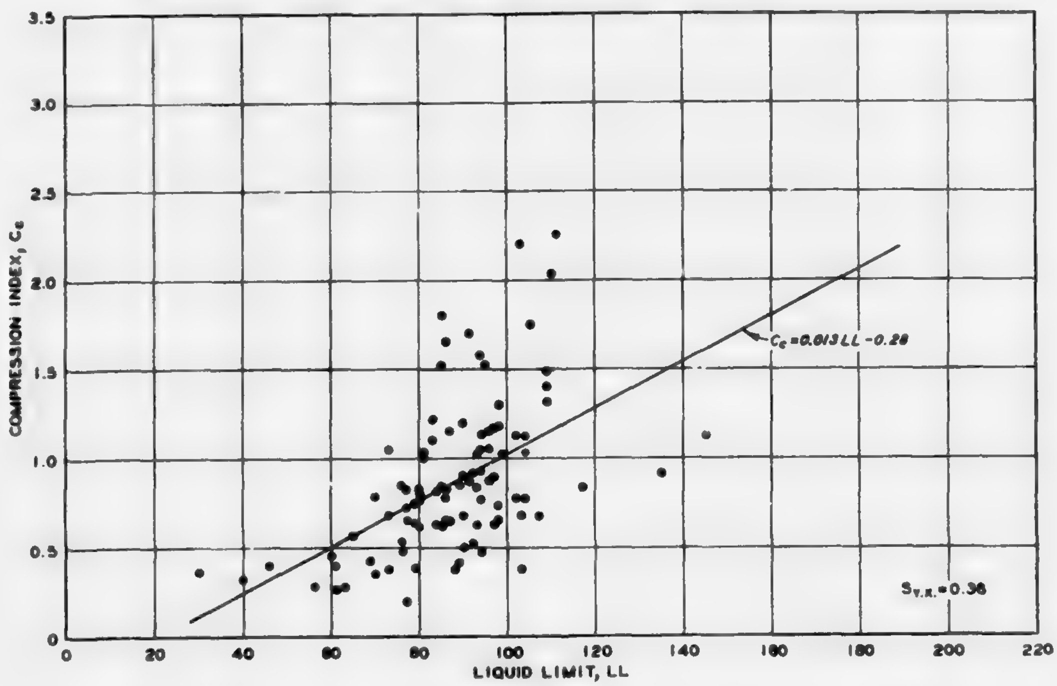


b. Compression index versus liquid limit

Fig. 4-20. Compression index correlations for orgainc backswamp deposits



a. Compression index versus natural water content



b. Compression index versus liquid limit

Fig. 4-21. Compression index correlations for inorganic backswamp deposits

CHAPTER V

DISCUSSION OF RESULTS

5.1 Frequency Histograms

Typical properties of the deltaic deposits in the study area are summarized in table 2-1 and the variations in soil properties are provided by frequency histograms shown in figs. 2-2 through 2-20. They are presented for use by foundation design engineers who have limited laboratory data on deltaic soils and are in need of supplementary data. These histograms are intended only as supplemental data and for use in making rough approximations of soil properties. In no instances should these data be used in lieu of laboratory test data for making final foundation designs. If, however, the engineer selects data from the histograms based on his best judgment as to its applicability to his particular field conditions, the data should be quite useful in providing additional confidence in limited laboratory data. The mode values of the frequency distributions are the values that are most likely to occur for a given deposit. These values can be used in lieu of average values with reasonable confidence.

As pointed out in Chapter III, some soil properties such as water content, Atterberg limits, liquidity index, void ratio, and others, can be a function depending upon depth. Therefore, this should be considered if data are selected from the histograms. The engineer should select data within the range of plus or minus one standard deviation from the average but he must also take into account the effect of soil properties within the limits of variations that have been encountered.

Statistical presentations of data in the form of frequency histograms provide a better understanding of the variations in soil properties of deltaic soils.

5.2 Soil Properties Versus Depth

5.2.1 Natural Water Content

The range of natural water contents appeared to decrease slightly with depth and the range generally narrowed significantly as depths increased. Near the surface the water content data occupied a wide range, which can be attributed to the presence of organic matter.

5.2.2 Undrained Shear Strength

The undrained shear strengths of the deltaic soils, with the exception of the natural levee deposits, tend to increase with depth. Typical shear strength profiles are shown in figs. 3-1 through 3-6. They show that the shear strengths are either constant or decrease from the surface through a weathered zone and then increase linearly with depth. The undrained shear strengths of the natural levee deposits showed no variation with depth because of the overconsolidated nature of the soils represented by the test data.

Shear strength increase factors (s_u/p_o) were computed for each deltaic deposit with the exception of the natural levee deposits. They ranged from 0.22 ton per sq ft for the prodelta deposits to 0.35 ton per sq ft for the interdistributary deposits. Shear strength increase factors were only developed for the normally consolidated soils and are not intended to apply to the slightly overconsolidated soil near the surface.

5.3 Correlations

5.3.1 Plasticity

The plasticity values of all the deposits except the backswamp deposits generally plotted close to but above the A-line, indicating a classification of CH or CL. Plasticity values for the backswamp deposits generally plotted nearer the A-line with an appreciable quantity plotting below it, thus indicating significant quantities of organic material present in these deposits. Reasonable correlations between plasticity index and liquid limit were developed for each deposit.

5.3.2 Specific Gravity

In general, it was found that for the deltaic soils, specific gravity increased with increases in plasticity. This holds true for the inorganic deltaic soils. However, the organic backswamp deposits displayed a reverse trend in that specific gravity decreased with increases in plasticity. The correlations shown in figs. 4-4 through 4-7 are considered to be reasonably typical for each deposit. Appreciable scatter, however, is noted in the data used for the correlations for intradelta and the organic backswamp deposits as shown in figs. 4-5b and 4-7b, respectively. The correlations between specific gravity and plasticity index provide a means of estimating specific gravity from relatively economical Atterberg limit tests. Extrapolation of the regression lines is not recommended. Reasonable assurance can be obtained from values selected from the regression lines only within the range of data.

5.3.3 Undrained Shear Strength

Reasonable correlations were established between undrained shear strength and liquidity index as shown in figs. 4-8 through 4-10. Although appreciable scatter is noted in the data shown in the plots for the point bar, inorganic backswamp, and intradelta deposits it is considered that reasonable estimates of undrained shear strength can be made from the nonlinear curves of regression. A correlation was developed for the slightly overconsolidated natural levee deposits (fig. 4-9), which indicated that such correlations can be made regardless of degree of consolidation of the soil. Nevertheless, estimates based on these correlations should be considered as only rough estimates of shear strength and should be verified by other correlations and laboratory data. The use of these correlations in conjunction with the s_u/p_o ratio should result in a predicted shear strength that can be used with more assurance.

Plasticity index was plotted versus s_u/p_o ratio in fig. 4-12. It has been suggested that a correlation exists between s_u/p_o and plasticity.[8] Correlations were developed for several of the deltaic deposits, however, the data indicated both negative, positive, and no correlations. This is in contrast to the positive correlation of such a statistical relation between s_u/p_o and plasticity reported in reference 8. The reason for the variation between s_u/p_o and plasticity indicated for the deltaic soils is not fully understood. However, such correlations of s_u/p_o with plasticity have been questioned previously by Kenney,[24] and Narain and Ramanathan.[25] Kenney suggests that the plasticity index of a soil is measured for remolded soil by tests that

depend on the mineralogical nature of the constituent particles of the soil; whereas, the undrained shear strength is dependent on soil structure. Although correlations were developed between s_u/p_o and plasticity index, they do not completely verify the theory that positive correlations exist between these two variables. Additional studies are needed to provide more conclusive data in this regard. A greater quantity of data would probably have permitted a more accurate and conclusive study of these properties. Estimates of undrained shear strength based entirely on the regression lines shown in fig. 4-12 are not recommended.

5.3.4 Drained Shear Strength

The small quantity of S-data available for the natural levee, intradelta, and prodelta deposits provides only inconclusive results. No S-test data were analyzed for the point bar or the interdistributary deposits. Adequate data were available for a reasonable correlation between ϕ' and plasticity index for the normally consolidated inorganic backswamp deposits.

Based on the data shown in figs. 4-13 and 4-14, there appears to be a relation between the effective angle of internal friction ϕ' and PI as suggested by Bjerrum and Simons,[22] and others. However, appreciable scatter of the data is noted in the plots. The scatter in fig. 4-13 may be attributed to the fact that data from the slightly overconsolidated natural levee deposits and data from unidentified deposits are included.

Correlations are shown for the normally consolidated inorganic backswamp deposits (fig. 4-14a). Although appreciable scatter of data

occurs about the line of regression, it is considered that ϕ' values can be estimated from this correlation with reasonable assurance. Correlations for the overconsolidated inorganic backswamp deposits are shown in fig. 4-14b. Although there appears to be a good correlation between ϕ' and PI, insufficient data are presented to permit a conclusive analysis.

5.3.5 Consolidation Properties

Simple correlations between natural water content and compression index and between liquid limit and compression index were found to exist for the deltaic deposits (figs. 4-18 through 4-24). The correlations appear to be quite good, although a greater quantity of data would have provided a better basis for more conclusive opinions. Appreciable scatter is noted in the data shown in all the plots. The correlations between compression index and natural water content, and compression index and liquid limit are markedly different for overconsolidated soils shown in fig. 4-20 than for normally consolidated soils shown in figs. 4-15 through 4-19 and 4-21. Such correlations for overconsolidated soils appear to be best represented by nonlinear curves of regression. Sufficient data were not available to define clearly the correlations for the overconsolidated natural levee deposits. The correlations shown in fig. 4-15 appear quite good, even though based on a limited amount of data. A probable explanation for the wide scatter of data is that water content and liquid limit determinations were made on materials that did not truly represent the consolidation test specimen.

CHAPTER VI

CONCLUSIONS

Analysis of the soil test data representing important segments of fine grained cohesive deposits of the deltaic plain of the Mississippi River and backswamp deposits of the Atchafalaya River indicates that a number of important relationships and trends exist that appear to be characteristic of the deposits studied. Based on the data presented in this report, the following conclusions appear warranted:

a. Natural water contents appear to decrease slightly with depth and the range generally narrowed significantly as depths increased.

b. Undrained shear strengths for the normally consolidated deltaic soils tend to increase with depth. Based on the shear strength versus depth plots, the average shear strength increase factors (s_u/p_o ratio) varied from 0.22 to 0.35 for the deposits studied.

c. A study of the variation of s_u/p_o and plasticity index for the various deposits indicates that such a correlation does not necessarily exist even for soils of the same geologic origin.

d. Undrained shear strengths from Q-tests are related to liquidity index. Thus reasonable estimates of Q-strengths can be made from the natural water content and Atterberg limit tests.

e. The relationship between liquid limit and compression index and also water content and compression index was found to be

linear for all deposits studies, except the backswamp deposits, which gave nonlinear relationships.

f. Correlations have been developed between the following:

   (1) Plasticity index and liquid limit.

   (2) Plasticity index and specific gravity.

   (3) Liquidity index and undrained shear (s_u) strength.

   (4) Plasticity index and drained shear (s_d) strength.

   (5) Natural water content and compression index.

   (6) Liquid limit and compression index.

g. It is thought that much of the scatter of data for correlation of natural water contents and liquid limits with compression index is due to difficulties in obtaining materials for liquid limit and water content determinations that truly represent the consolidation test specimen.

h. Correlations presented in this report may be used with confidence for preliminary estimates and planning of investigations.

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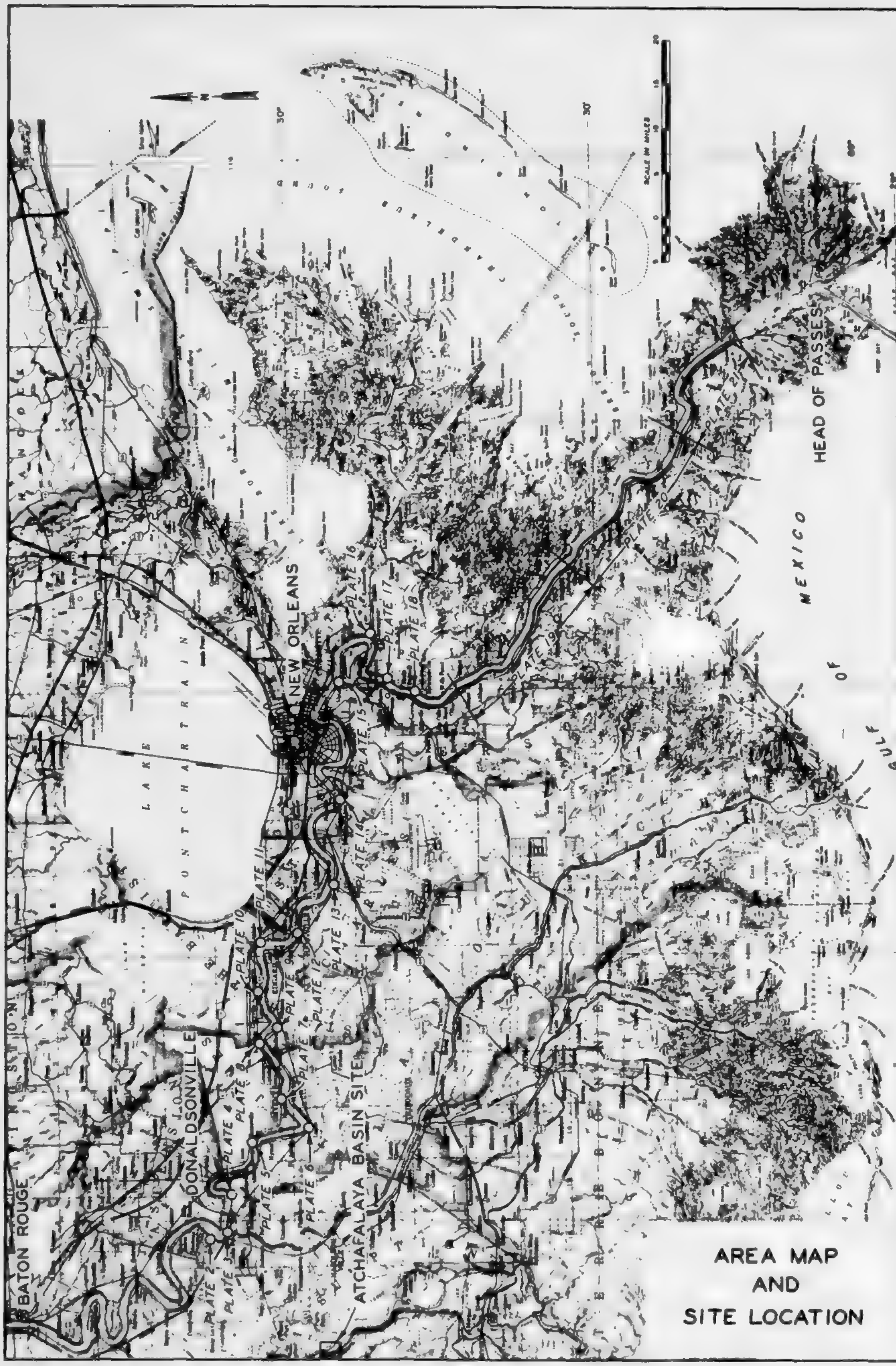

AREA MAP
AND
SITE LOCATION

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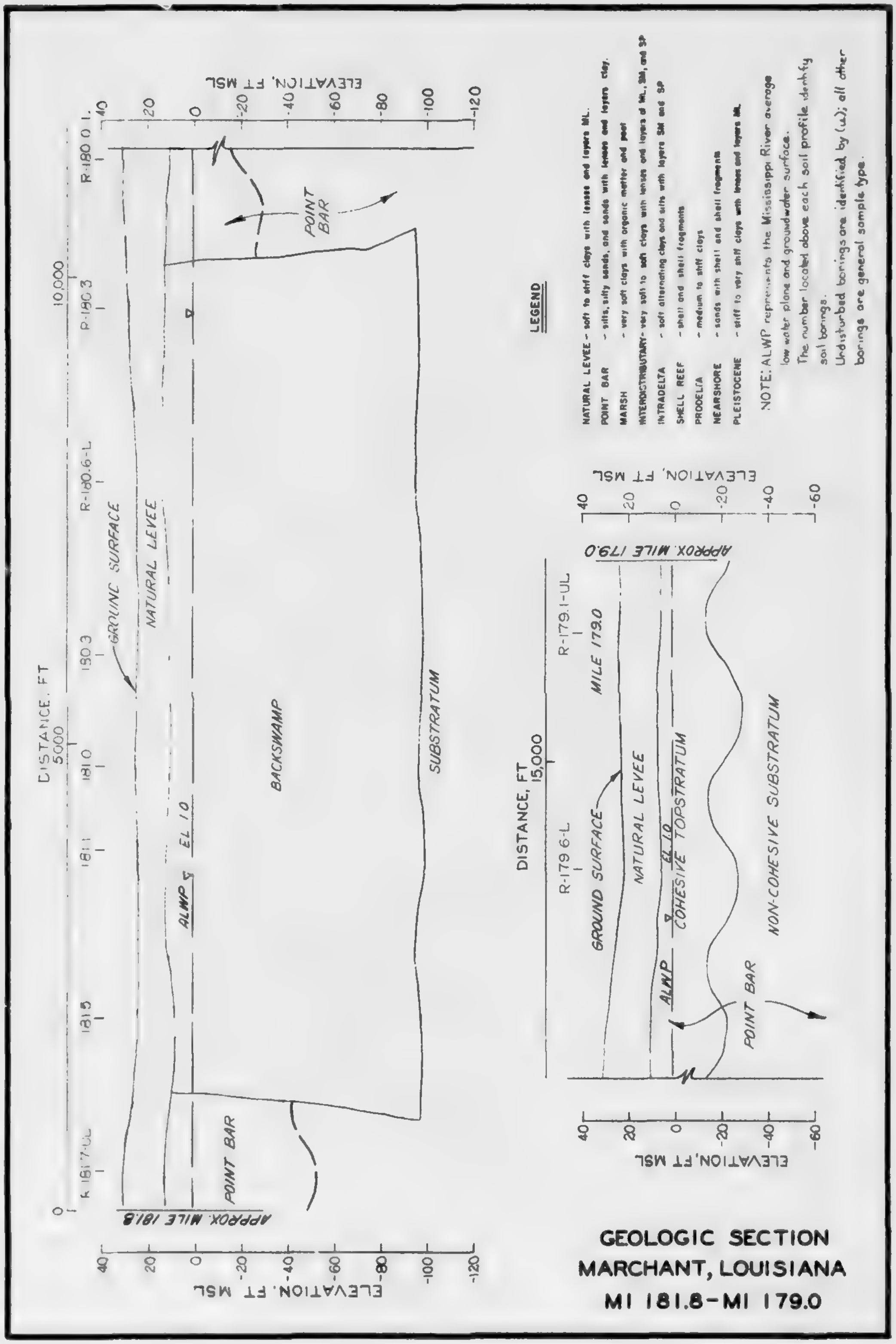

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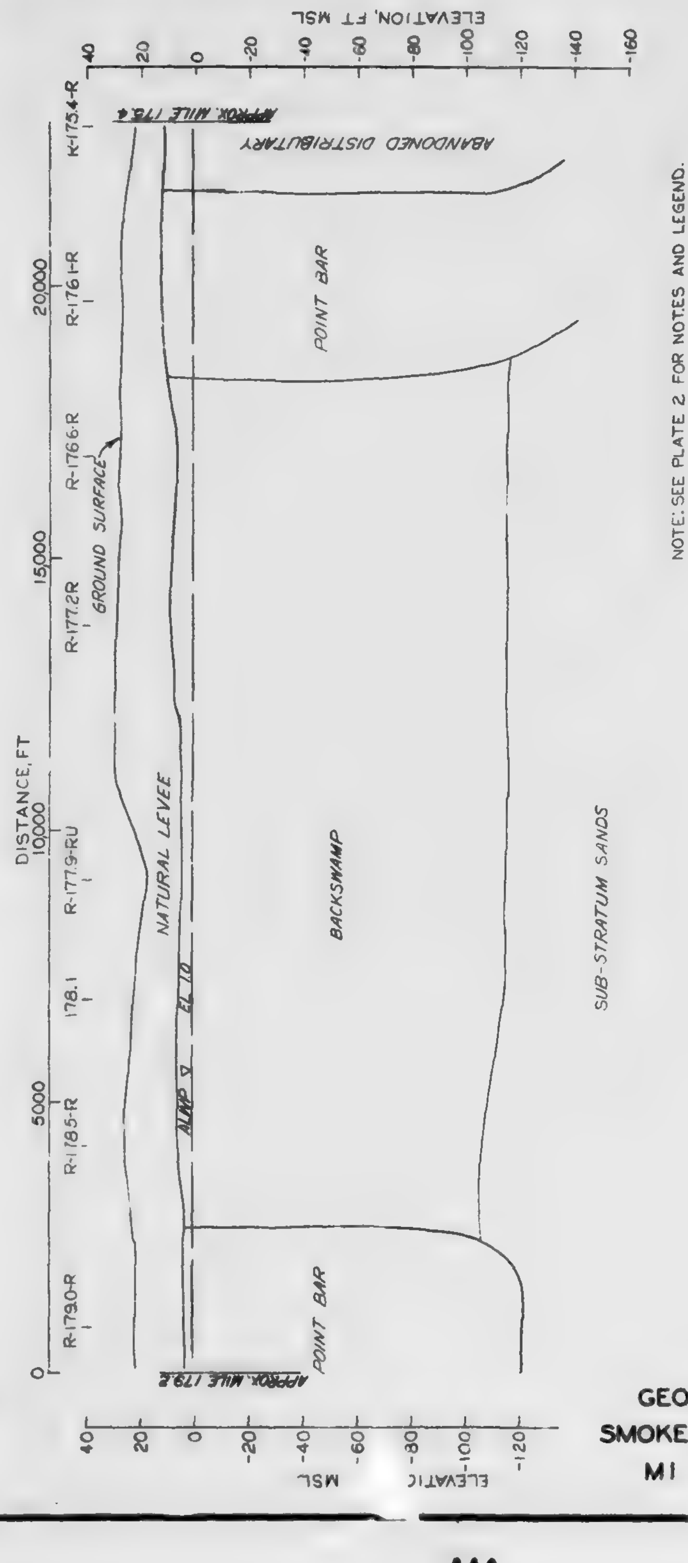

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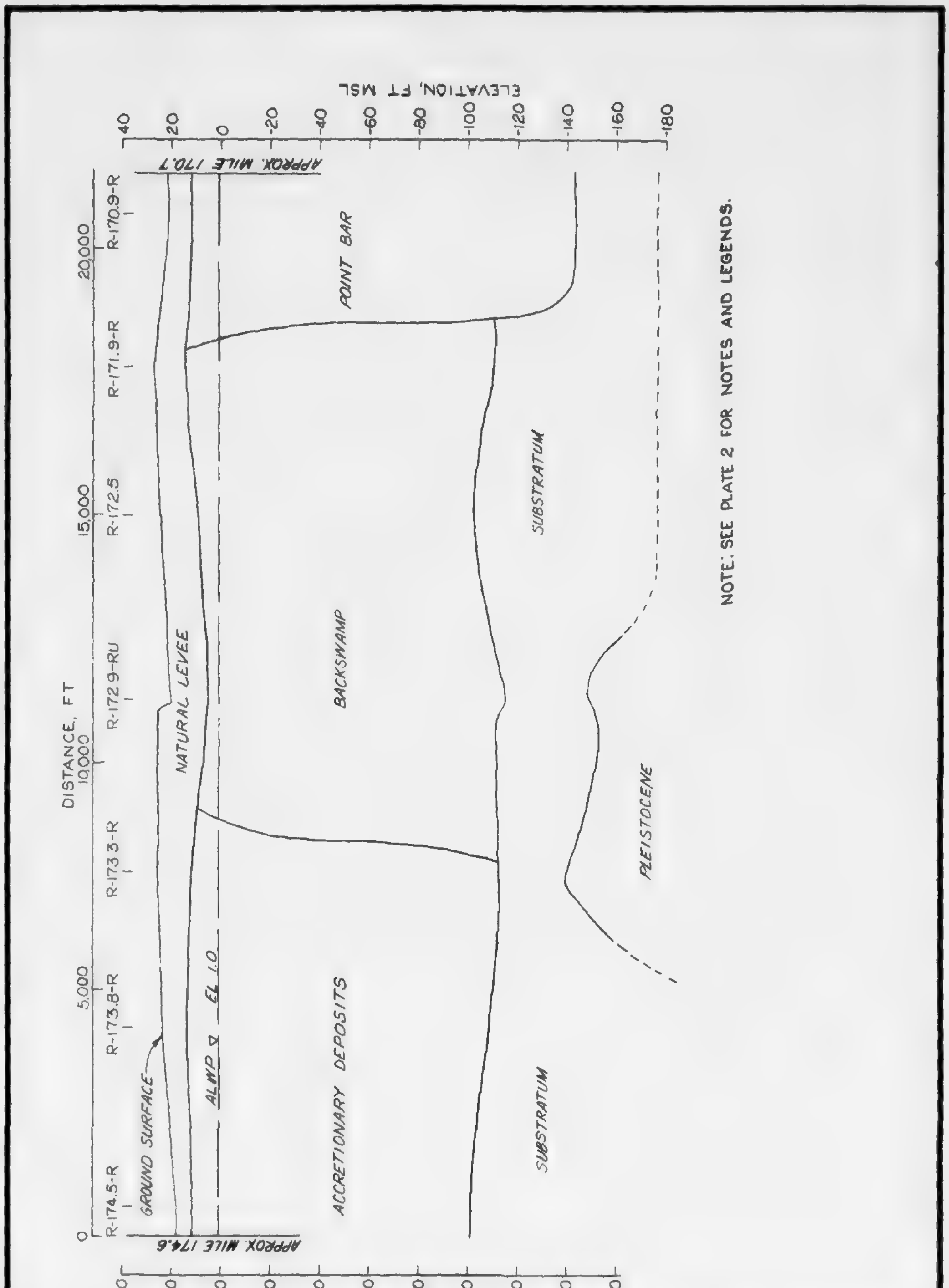

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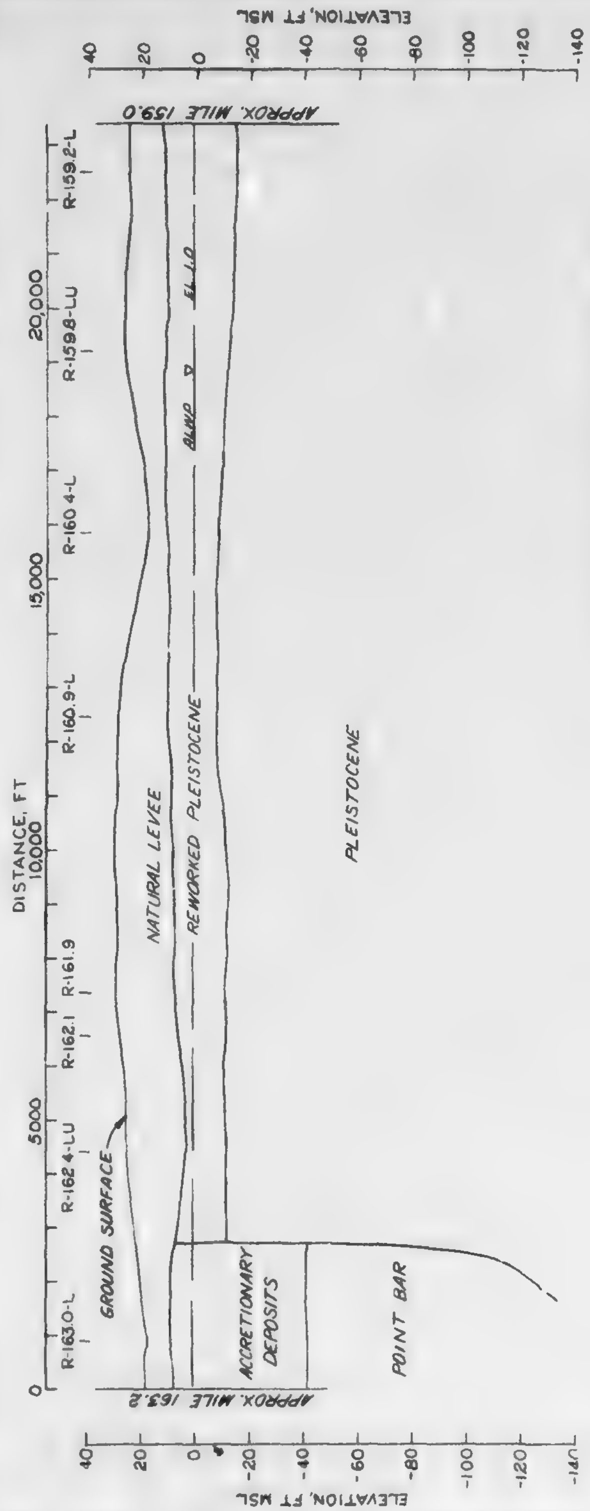

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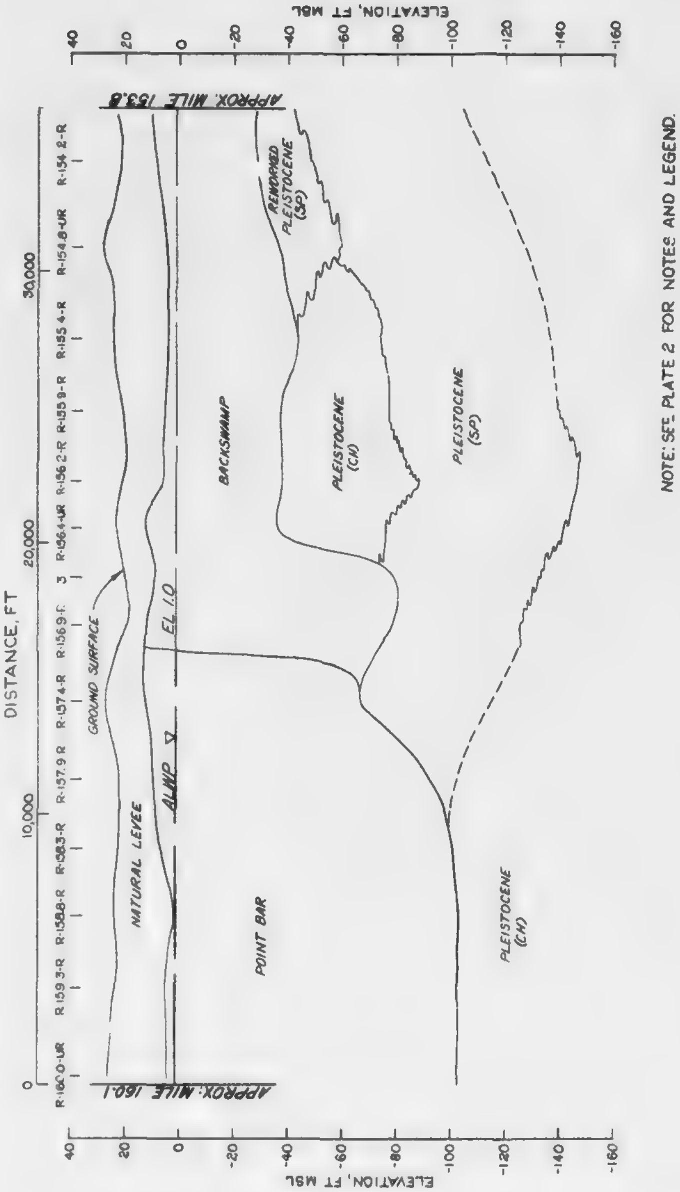

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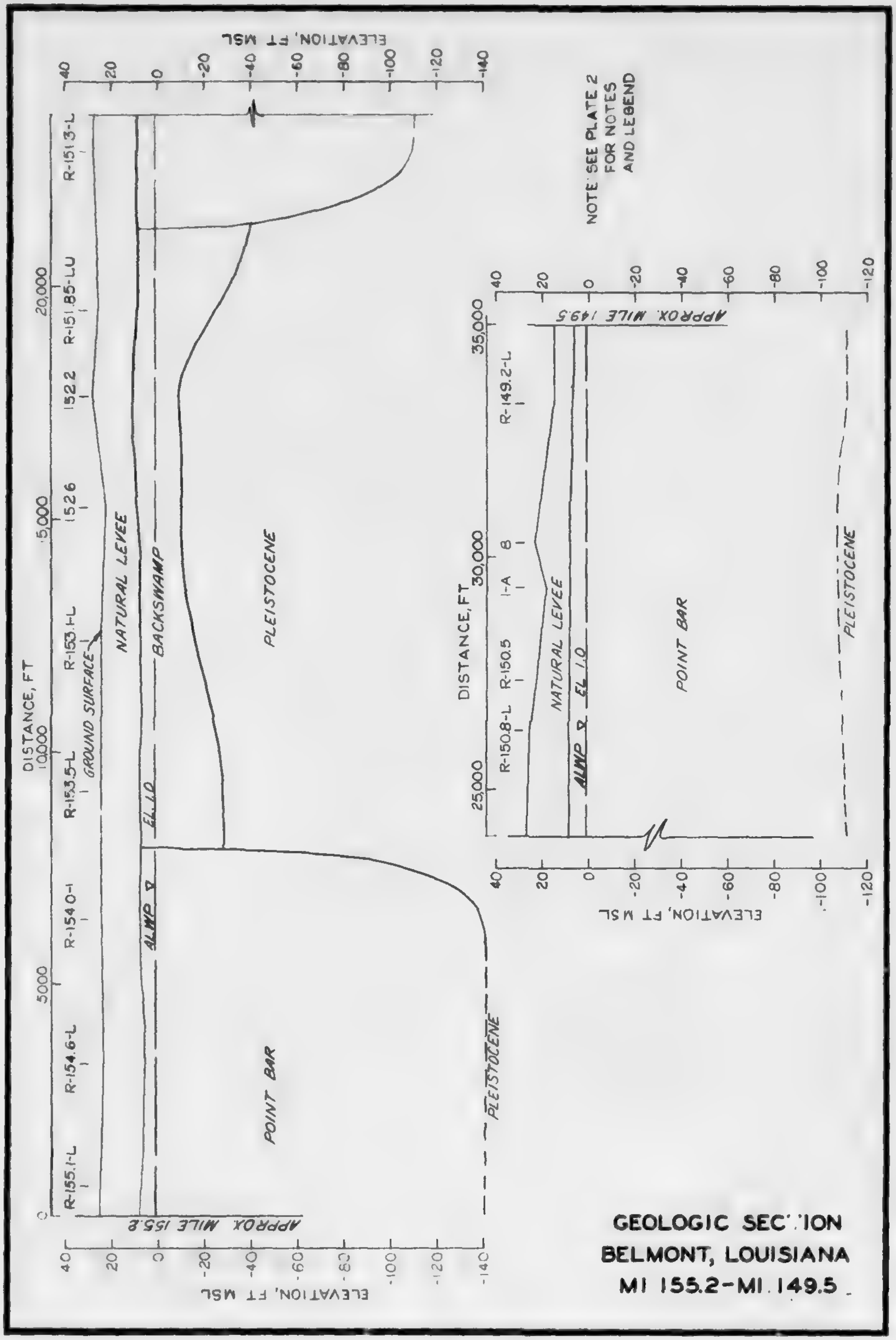
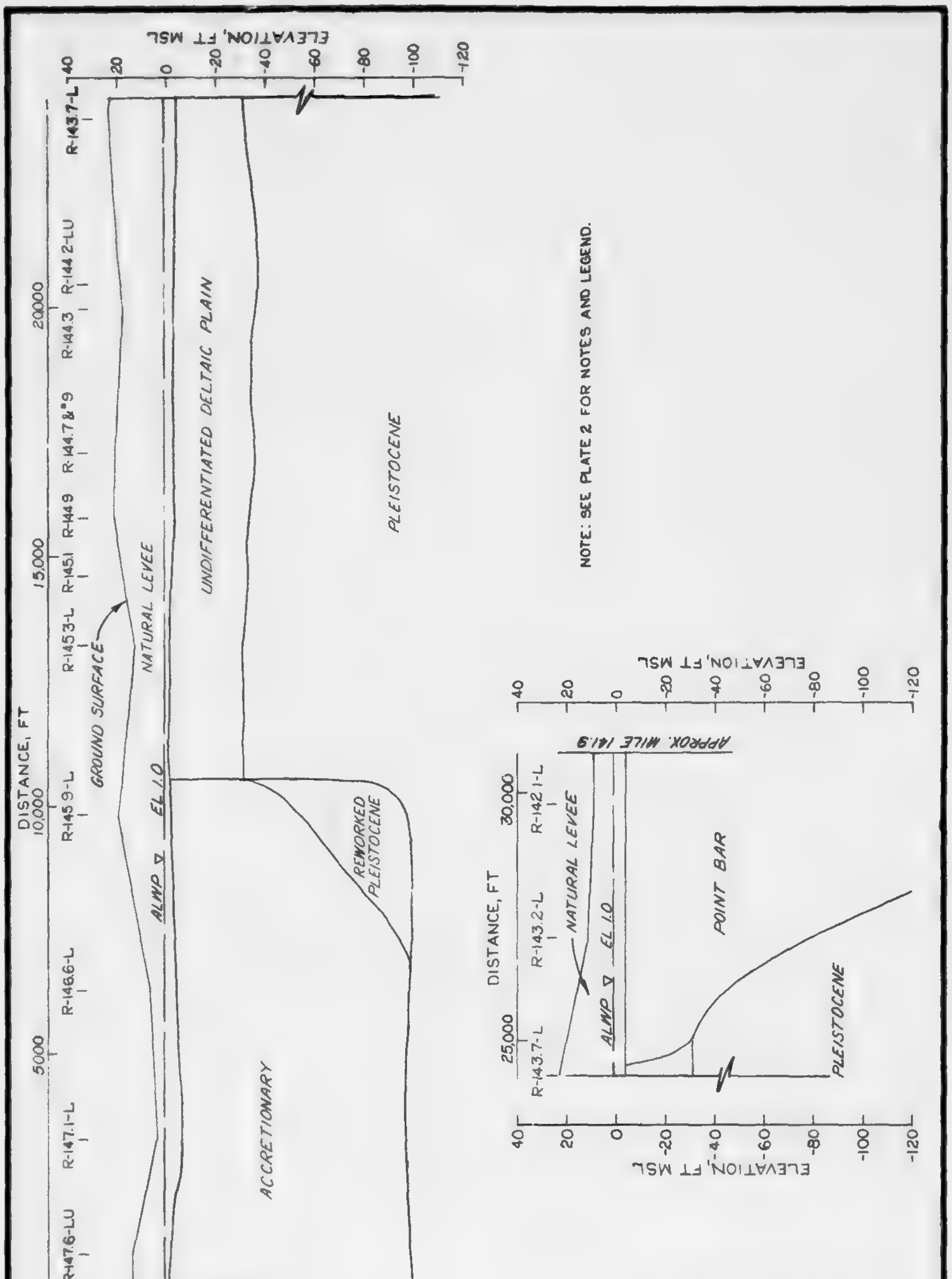


GEOLOGIC SEC'.ION
BELMONT, LOUISIANA
MI 155.2–MI 149.5

PLATE 7.



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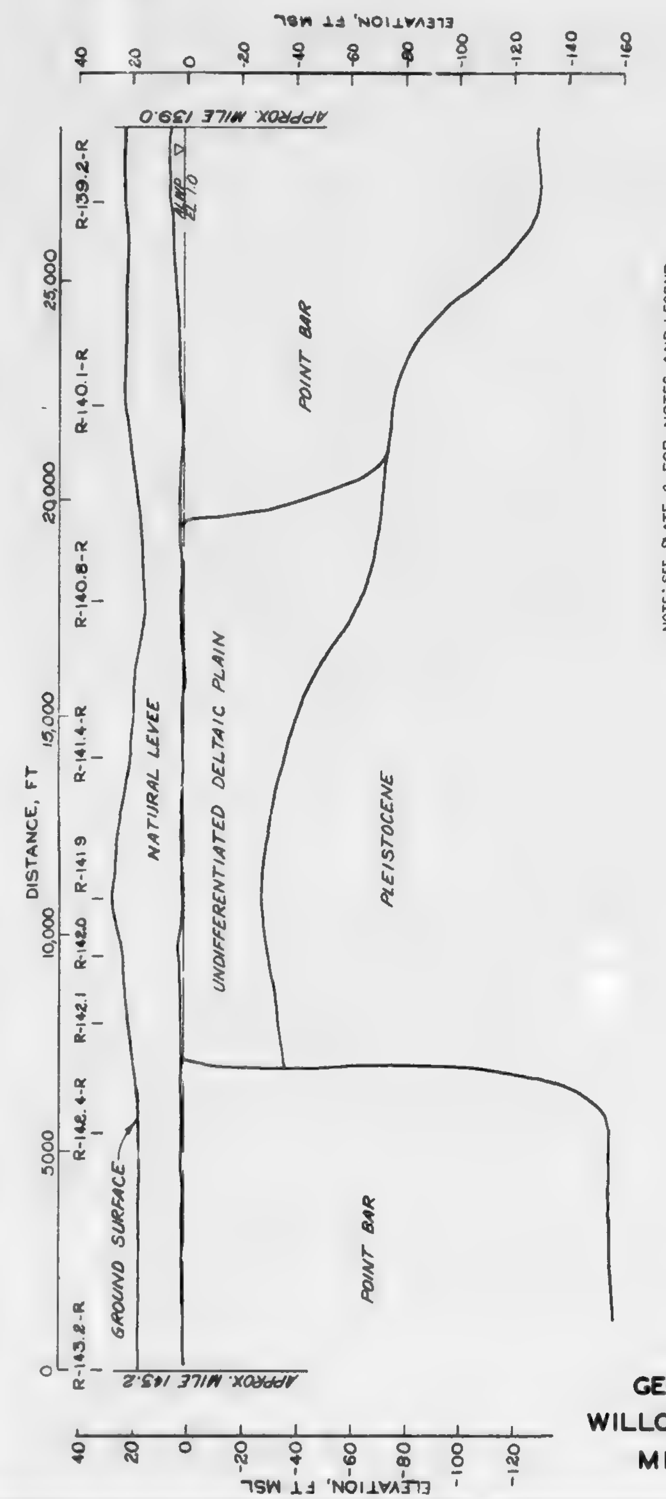
MI 147.8 – MI 141.9



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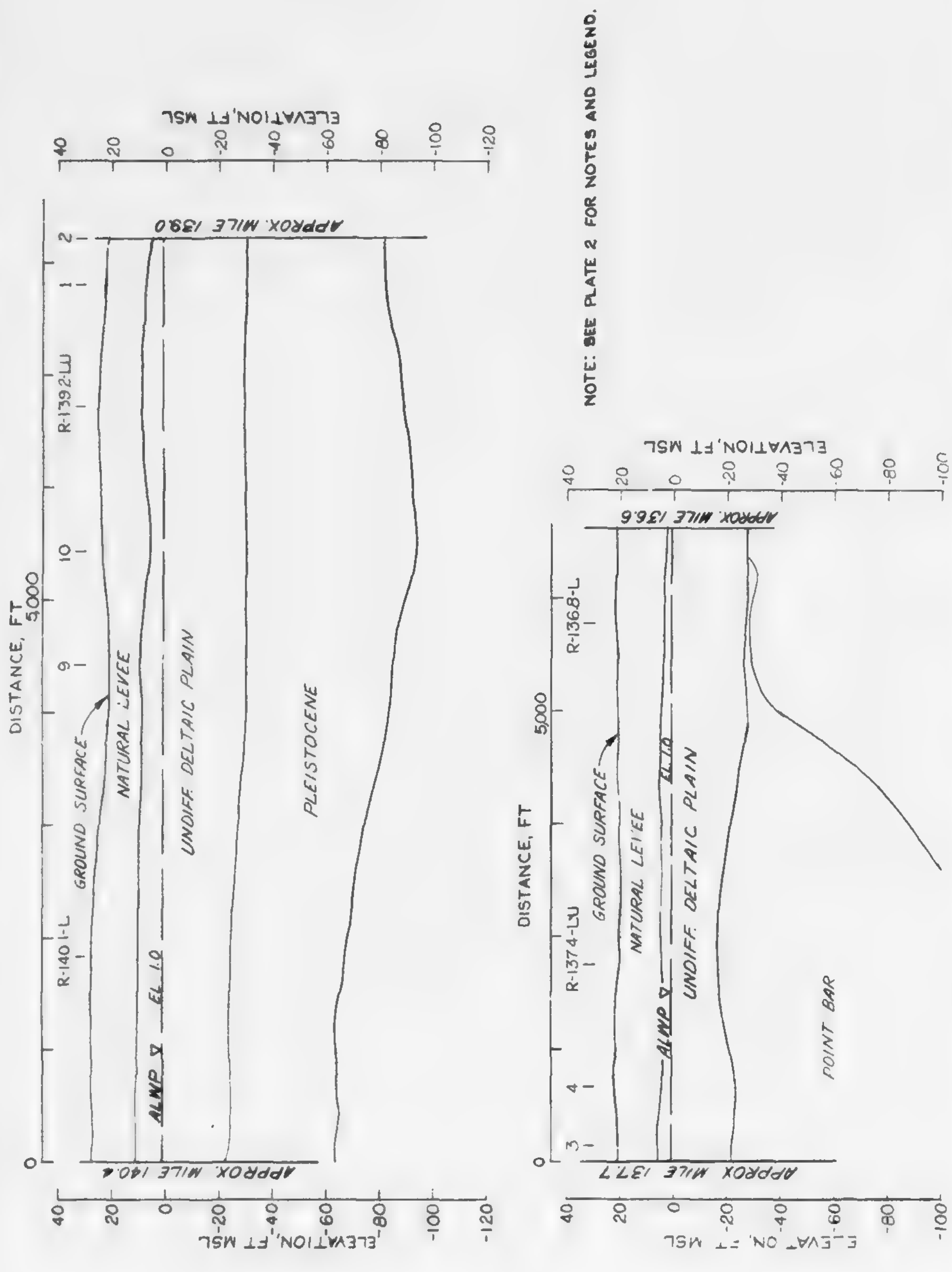
MI 143.2–MI 139.0



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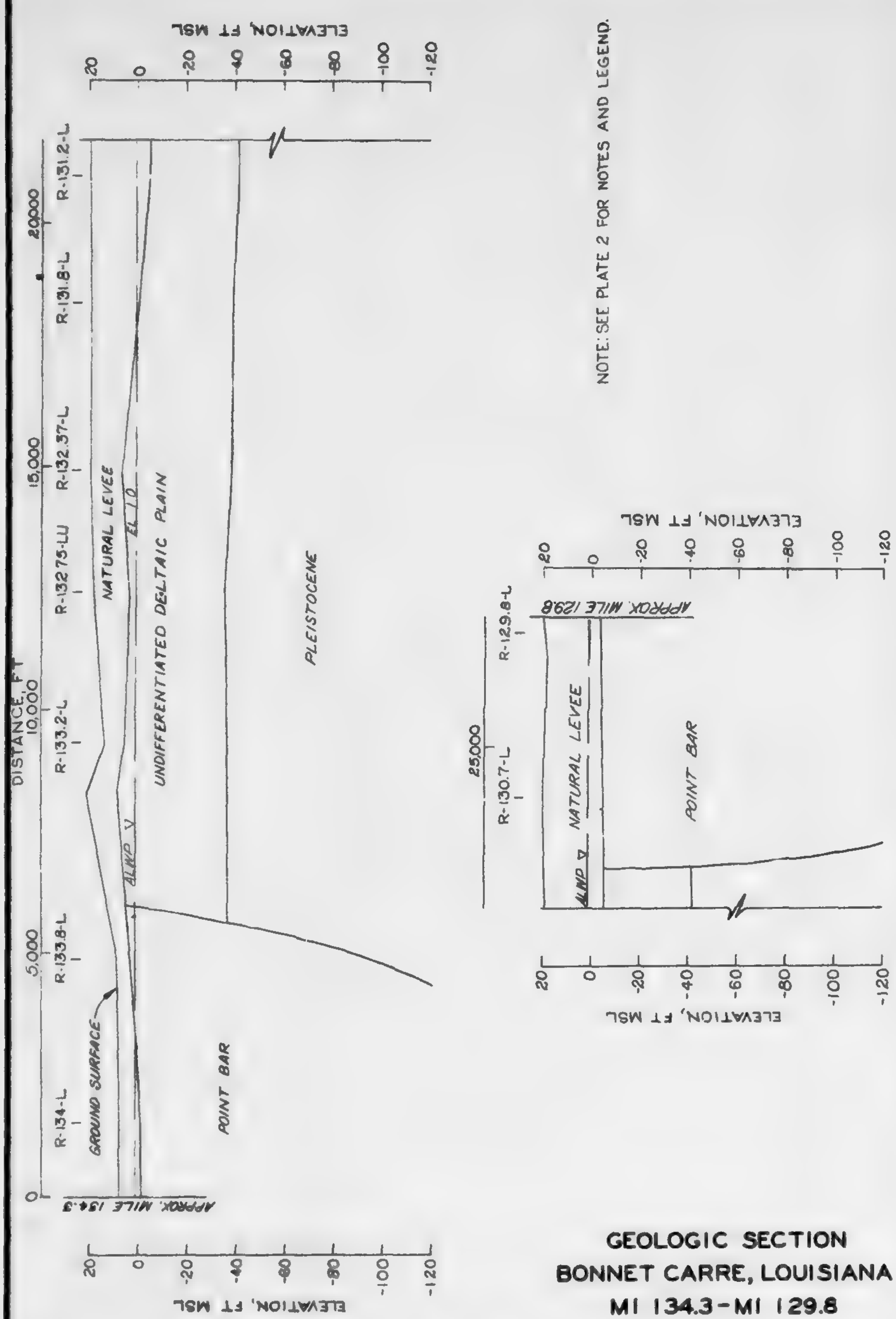
RESERVE, LOUISIANA
MI 140.4–MI 136.6

PLATE 10



GEOLOGIC SECTION
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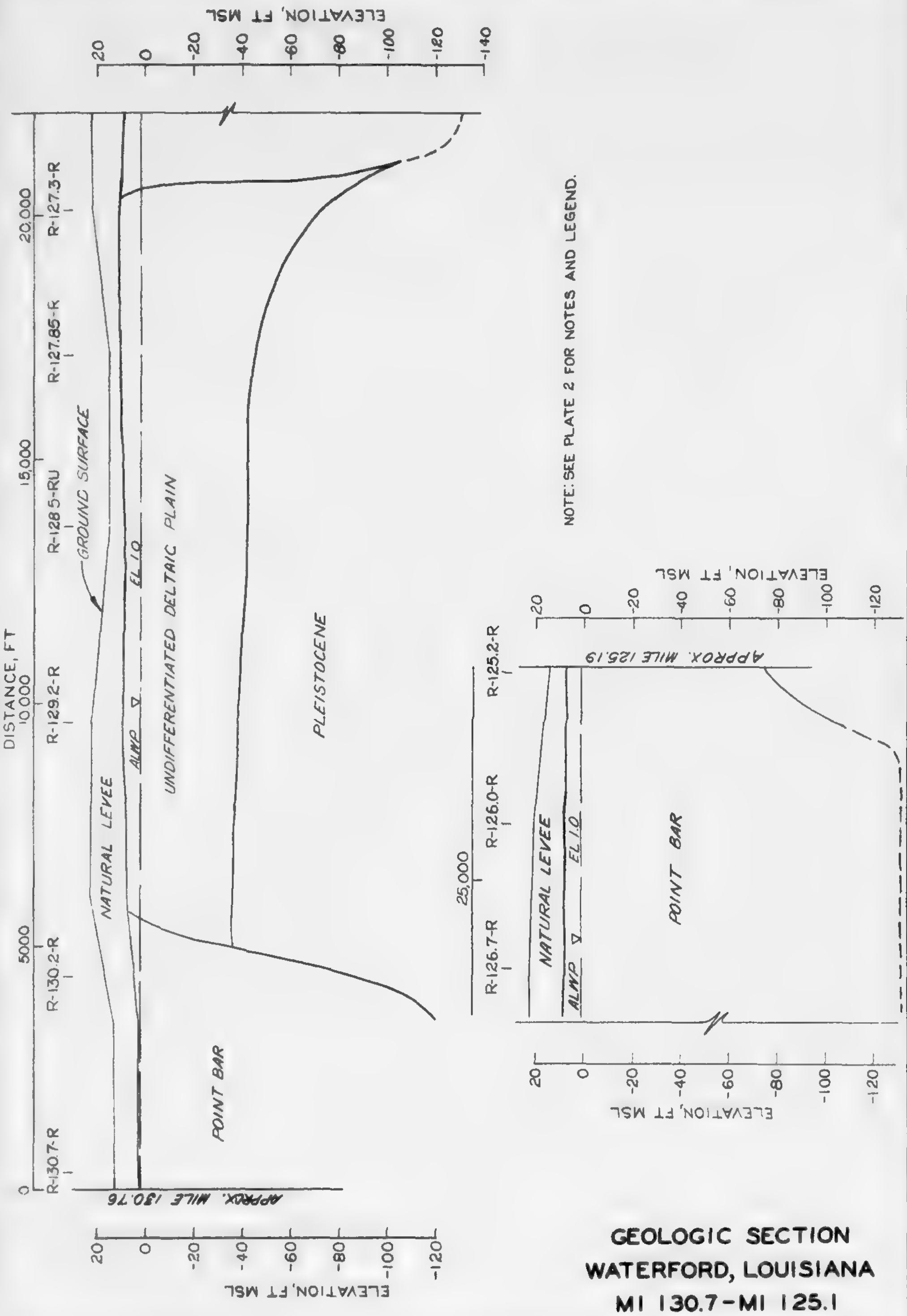
MI 134.3–MI 129.8

PLATE 11



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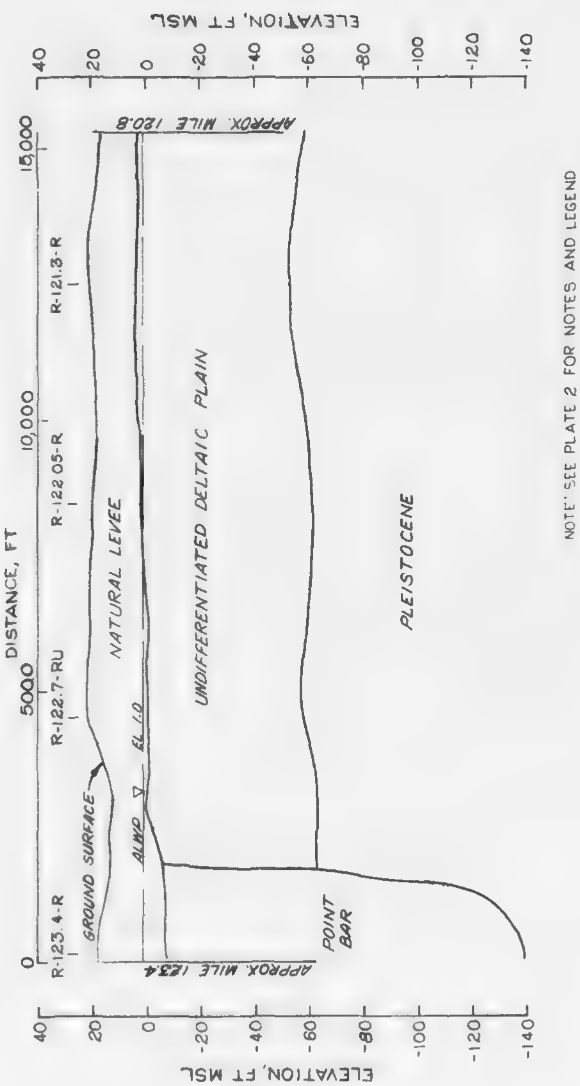
MI 130.7–MI 125.1

PLATE 12



GEOLOGIC SECTION
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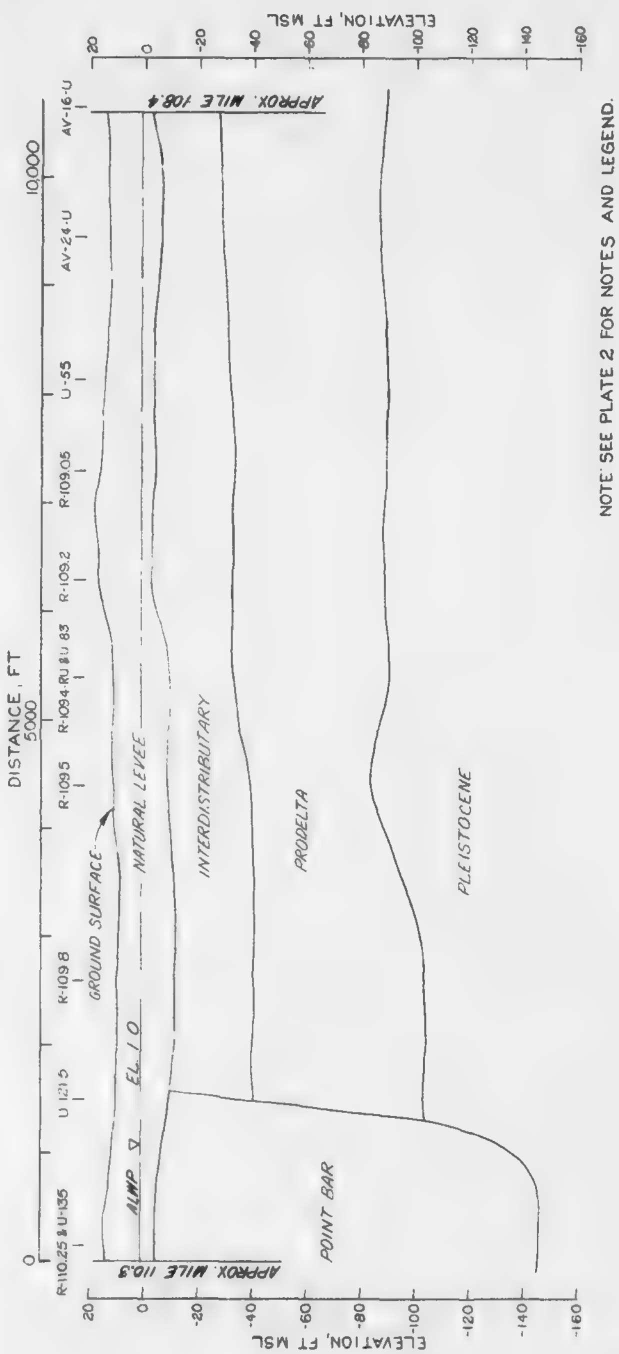
MI 123.4–MI 120.8



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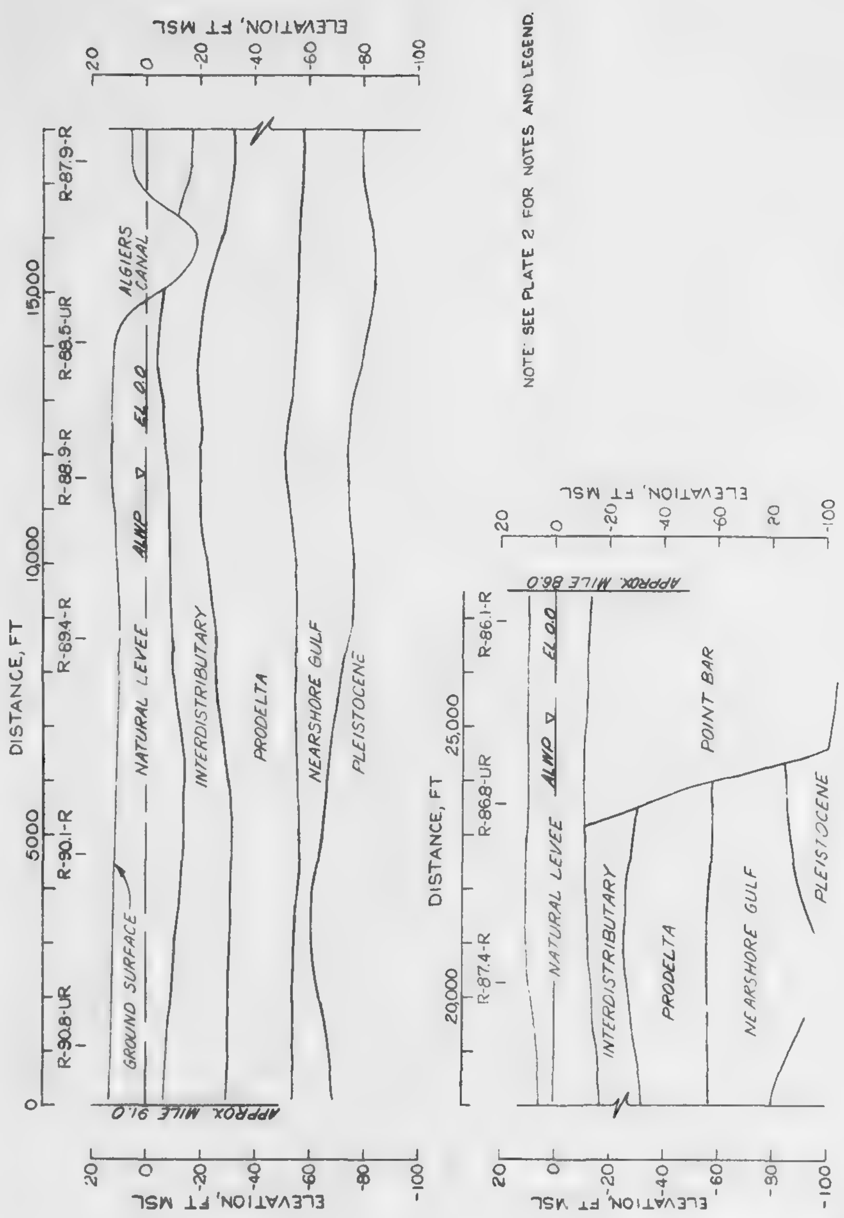

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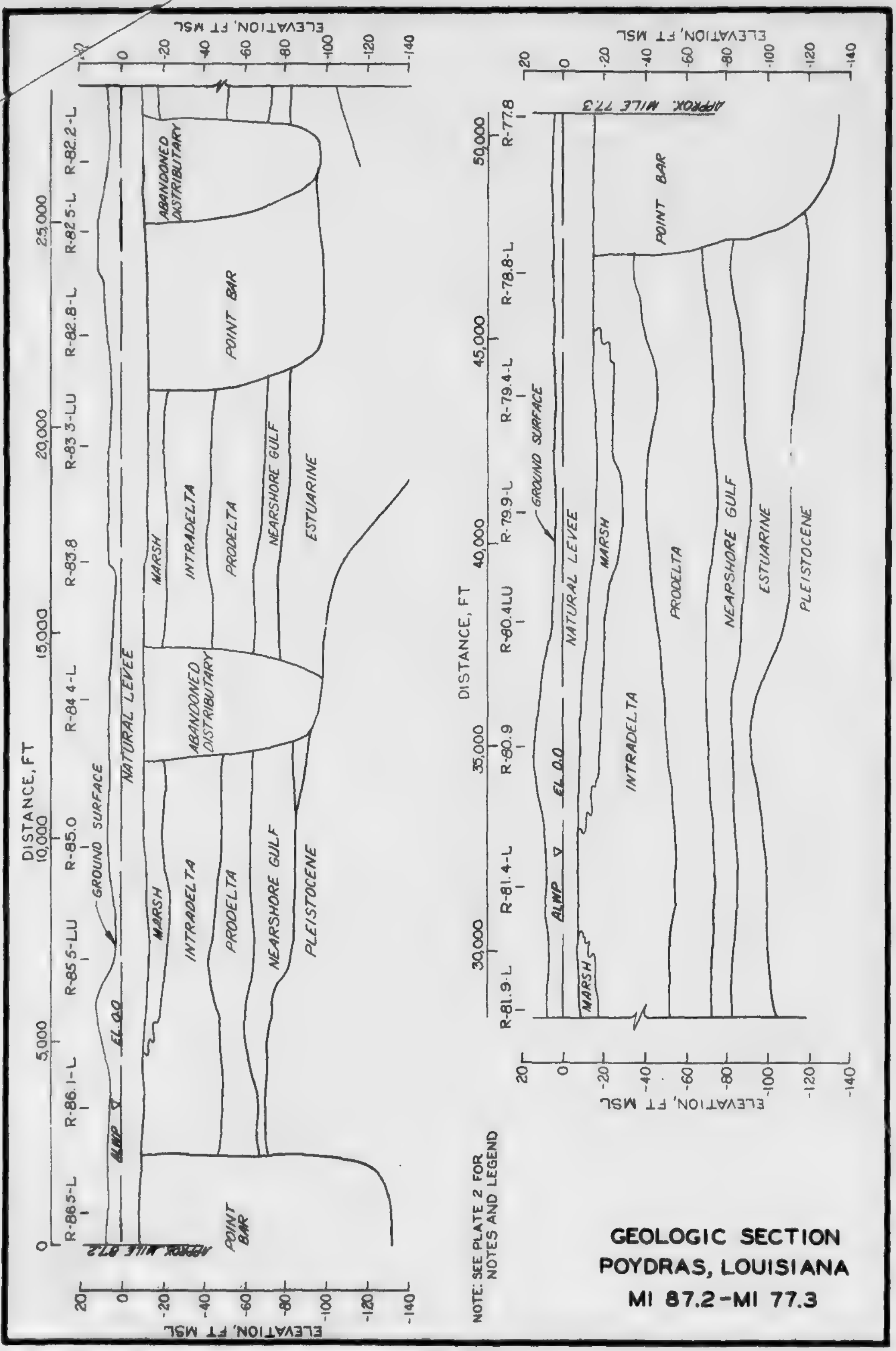

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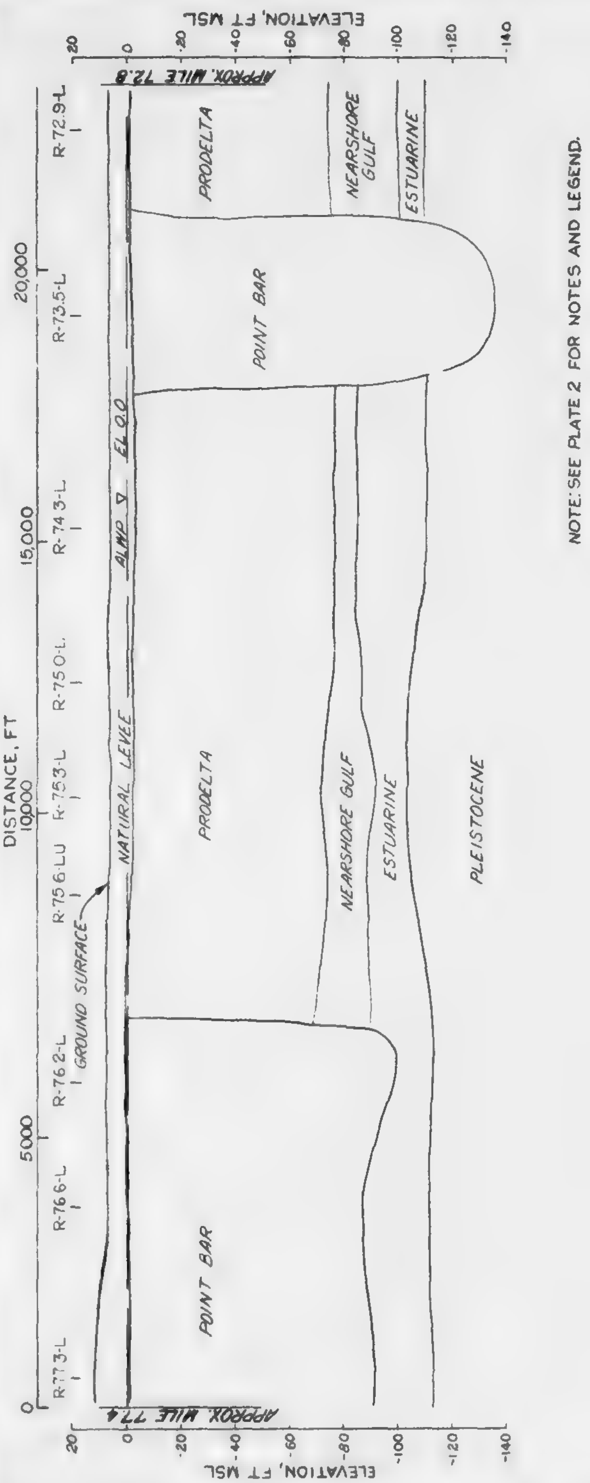
MI 87.2–MI 77.3

PLATE 16



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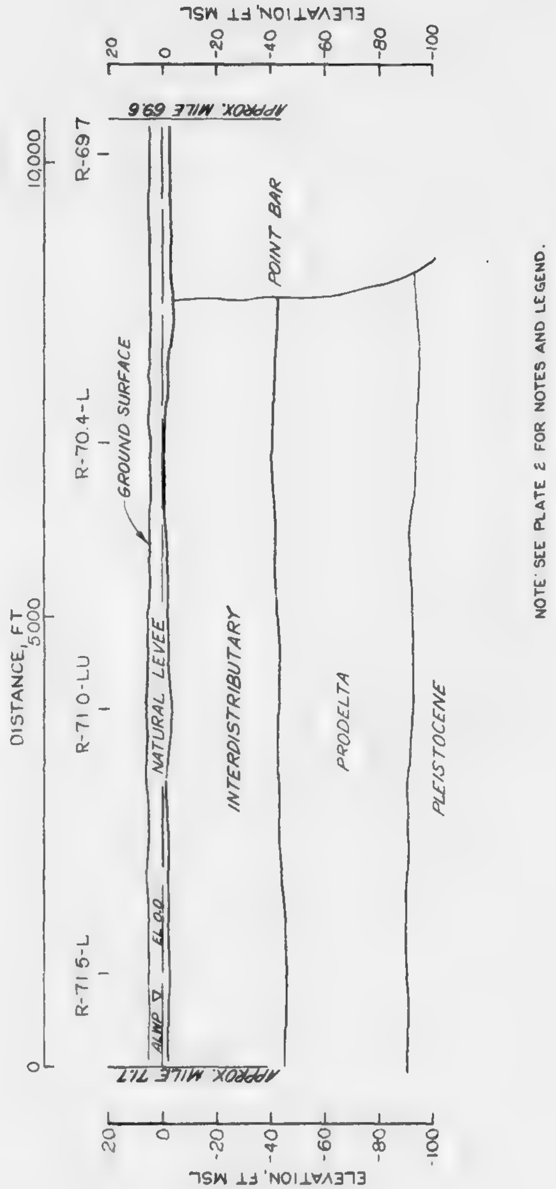
MI 77.4–MI 72.8



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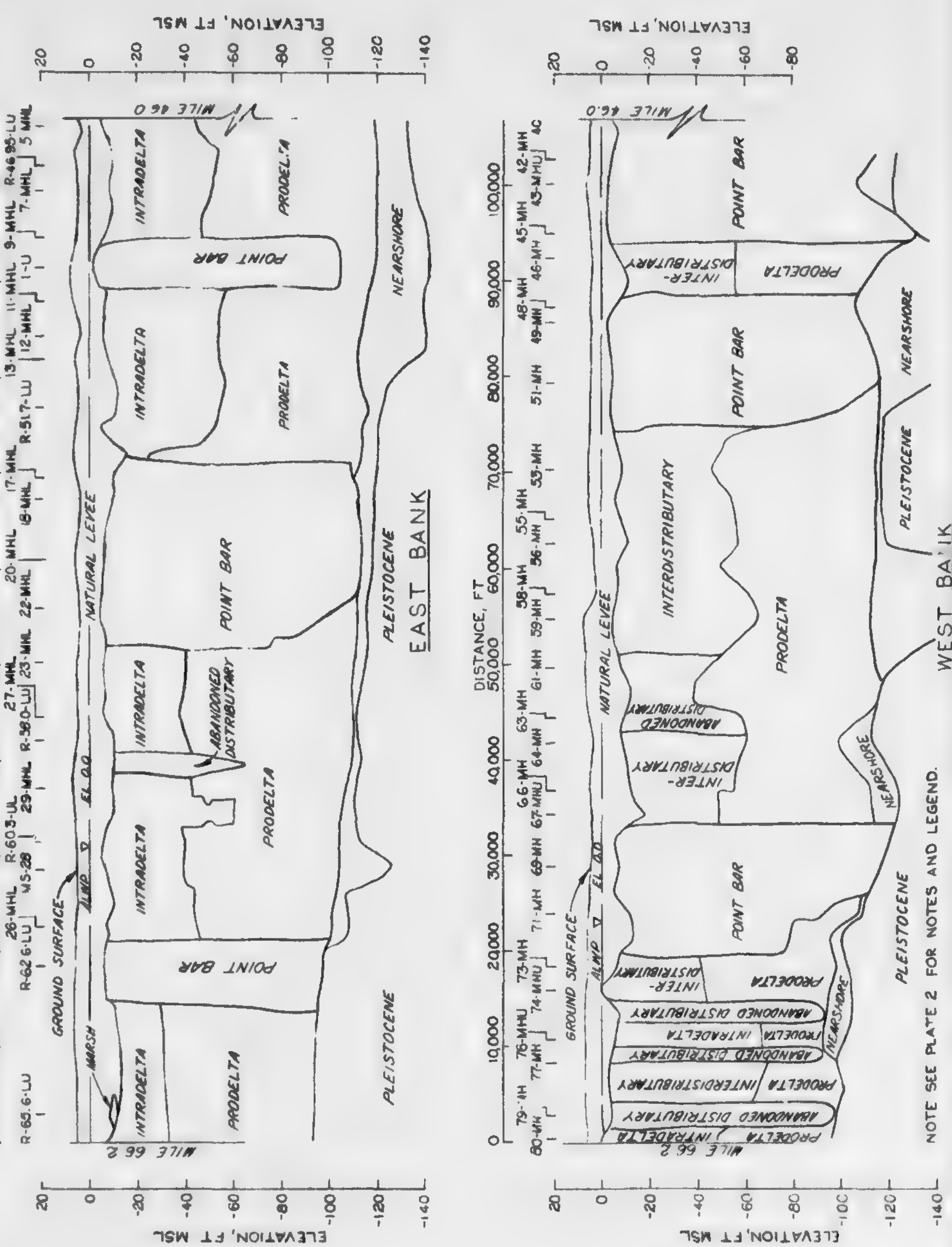
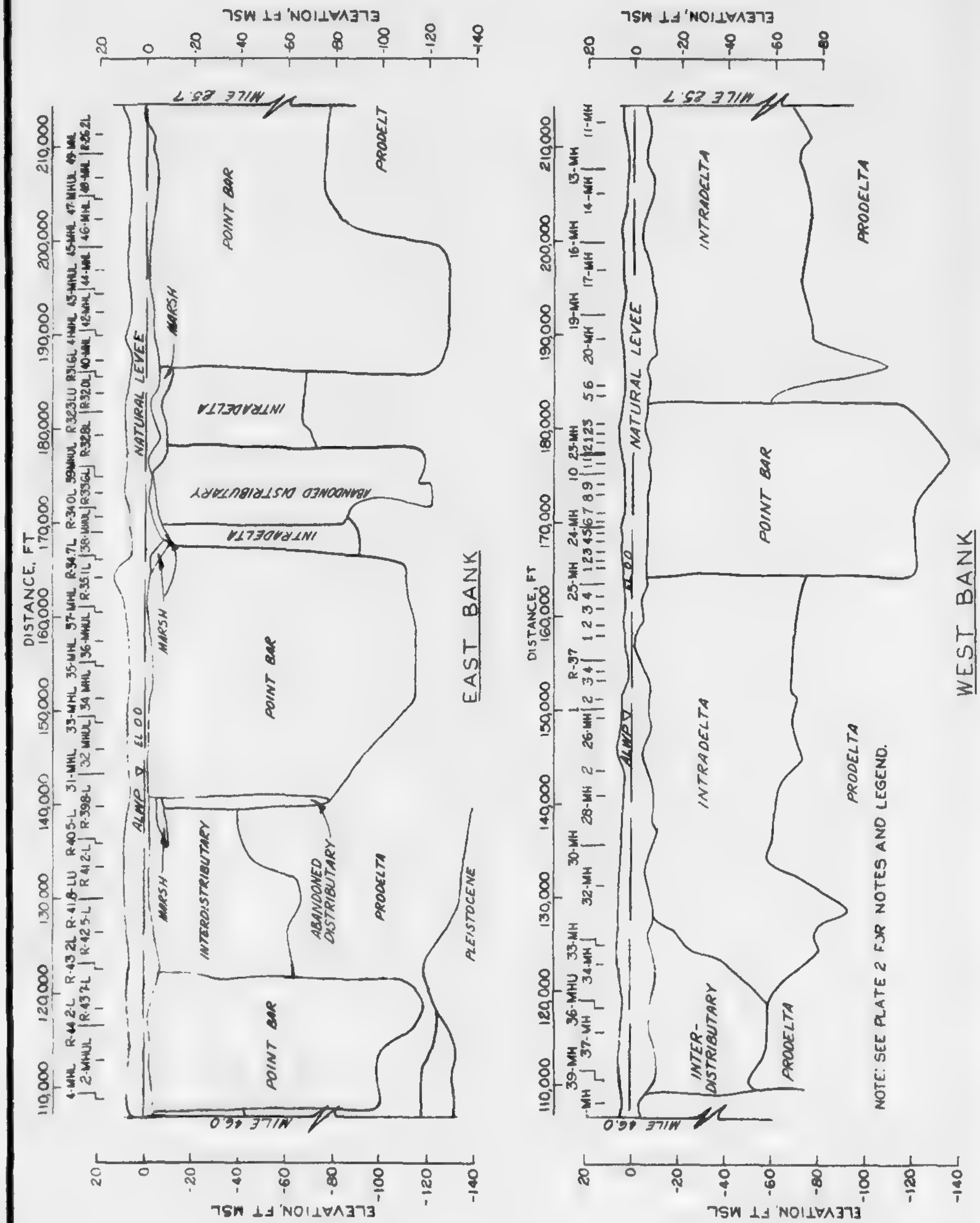
MI 71.7–MI 69.6

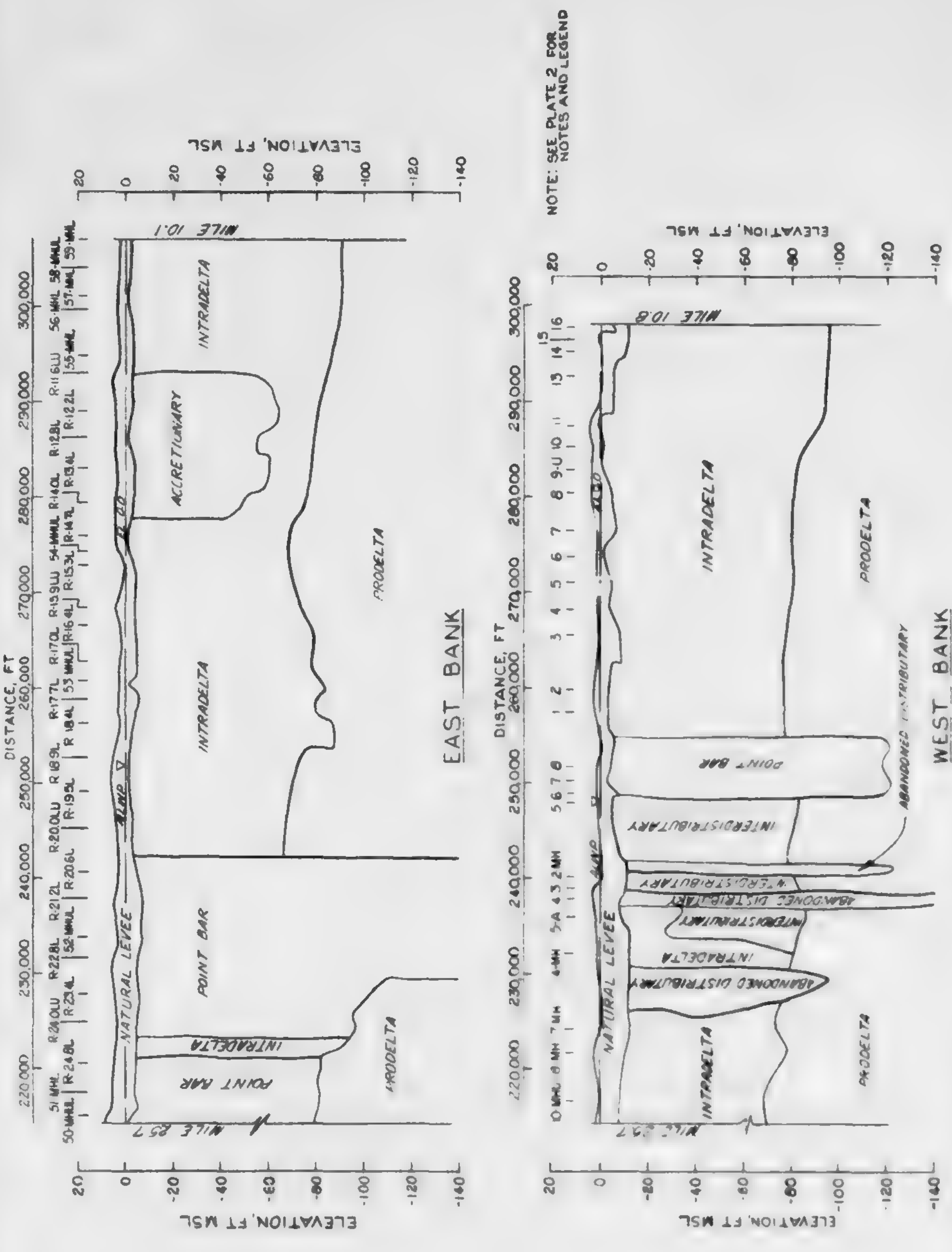


GEOLOGIC SECTIONS
MI 66.2–MI 46.0



GEOLOGIC SECTIONS
MI 46.0 - MI 25.7

PLATE 20



GEOLOGIC SECTIONS
MI 25.7 – MI 10.1

APPENDIX A

DEFINITION OF STATISTICAL TERMS

Frequency Histogram

N	Number of measurements, observations, or test values.
X_i	Individual value of a measurement, observation, or test value.
$\overline{X}$	Arithmetic mean or average, $\dfrac{\sum_{i=1}^{N} X_i}{N}$
σ	Standard deviation or root-mean-square deviation for a given group of values, $\sqrt{\sum_{j=1}^{N} (X_j - \overline{X})^2/N}$. The standard deviation represents a distance on the scale of values which is indicative of the amount of dispersion.
Kurtosis	Degree of peakedness of a distribution.
Leptokurtic	Description of a distribution having a relatively high peak.
Platykurtic	Description of a distribution having a relatively flat curve.
Mesokurtic	Description of a normal frequency distribution, a bell-shaped curve.
Symmetrical Shape	Normal bell-shaped curve.
Positive Skewness	The longer tail of the curve occurs to the right, skewed to the right.
Negative Skewness	The longer tail of the curve occurs to the left, skewed to the left.
Bimodal Shape	Frequency curve has two maxima.
Multimodal Shape	Frequency curve has more than two maxima.

Curve Fitting and Correlation

Curve Fitting	The problem of finding equations of approximating curves which fit given sets of data.
The Method of Least Squares	Finds the most probable value of a quantity for a set of measurements by choosing the value which minimizes the sum of the squares of the deviation of these measurements.
The Least Square Line	$Y = a_o + a_1 X$
The Least Square Parabola	$Y = a_o + a_1 X + a_2 X^2$
a_o , a_1 , and a_2	Constants determined by solving equations simultaneously.
Simple Correlation	Degree of relationship between two variables.
Positive Correlation	Where Y tends to increase as X increases.
Negative Correlation	Where Y tends to decrease as X increases.
Linear Correlation	All the points seem to lie near some straight line.
Nonlinear Correlation	All the points seem to lie near some curve.
Regression Line	A line which permits estimation of a variable Y based on a variable X . Thus the line is called a regression line of Y on X , since Y is estimated from X . In general the regression line or curve of Y on X is not the same as the regression line or curve of X on Y .

Standard Deviation from Regression

Commonly known as the Standard Error of Estimate. It is a measure of the scatter about the regression line. It has properties analogous to those of the histogram standard deviation. For example, if lines were constructed parallel to the regression line Y on X at respective vertical distances $S_{Y.X}$, 2 $S_{Y.X}$, and 3 $S_{Y.X}$ from it, 68%, 95%, and 99.7% of the sample points should be included between the lines.

Standard Deviation from Regression of Y on X:

$$S_{Y.X} = \sqrt{\frac{\sum(Y - Y_{es})^2}{N}}$$

Standard Deviation from Regression of X on Y:

$$S_{X.Y} = \sqrt{\frac{\sum(X - X_{es})^2}{N}}$$

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13. ABSTRACT

The purpose of this study was to analyze available data on selected cohesive deltaic plain soils and provide summaries of engineering data and correlations of engineering properties according to environments of deposition of the deltaic plain of the Mississippi River. The Mississippi River deltaic plain is that part of southeastern Louisiana that borders the Mississippi River from near Donaldsonville to Head of Passes. The deltaic plain is a complexly interfingered mass of fluvial, fluvial-marine, paludal, and marine deposits laid down in a variety of environments directly above the Pleistocene. This study focused attention on the deltaic plain deposits that are most important from an engineering standpoint. The deposits selected for study were the natural levee, point bar, and backswamp deposits of fluvial environment and the interdistributary, intradelta, and prodelta deposits of the fluvial-marine environment. Engineering data were obtained from data files on previous field and laboratory investigations of these soils for Corps of Engineers projects. The data were grouped according to environments of deposition based on the geological sections. No additional field or laboratory investigations were undertaken for this study. The data were collected and arranged in such a manner that it was possible to describe the data mathematically. The best-fit curves or lines, regression equations, and standard deviations presented for the data were developed by use of a computer. Based on the analyses, a number of important relations and trends appear to exist for the selected Mississippi River deltaic plain fine-grained cohesive deposits. Frequency histograms provide summaries of typical soil properties, and correlation plots show the relationships between the different soil properties. A number of correlations were made between Atterberg limits and data from relatively complex and more costly tests for physical properties. Reasonable correlations were found to exist between data from Atterberg limits tests and specific gravity, unconsolidated-undrained shear (Q) strengths, drained shear (S) strengths, and compression indexes (C_c). Also, reasonable correlations between plasticity index and liquid limit were developed for each deposit. Correlations between shear strength increase ratio (s_u/p_o) and plasticity index proved inconclusive. Important correlations between properties were found for soils of similar geologic origin and depositional environment. However, sufficient data were not available to establish conclusive relationships.

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